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OUTLINES

OF

PHYSIOLOGICAL PSYCHOLOGY

A TEXT-BOOK OF MENTAL SCIENCE

FOR

ACADEMIES AND COLLEGES

BY

GEORGE TRUMBULL LADD

PROFESSOR OF PHILOSOPHY IN YALE UNIVERSITY

SECOND EDITION

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PREFACE.

In the early part of 1887 I published the results of several years of research, in a book entitled "Elements of Physiological Psychology." The very gratifying reception almost immediately given to this work showed an extended and profound interest in the experimental and physiological study of mental phenomena. The signs of this interest have continued unabated until the present time; and the book has been widely adopted, both in this country and abroad, for private reading and for the instruction of classes.

Although the "Elements, etc." did not enter into the detailed history of discoveries and discussion of theories in the field of physiological psychology, it was necessarily somewhat voluminous and technical. For it aimed to give a summary of the entire field; and thus to render accessible the data and conclusions to be found, separated, only in scores or hundreds of larger and smaller monographs.

Almost immediately the demand arose for a smaller and less technical book, which should be adapted to aid the teacher with classes less mature, or able to afford less time to the subject. The present volume has been written for the express purpose of meeting this demand. It is not, however, a mere abridgment or revision of the larger work. While it, like the larger work, surveys the entire field, it omits all details, discussions, and references, which — however valuable for the purposes of more thorough mastery

— are likely to embarrass beginners of more limited patience and ability. The Parts (I. and III.) which treated of the nervous mechanism and of the nature of mind as related to the body, have been in this volume relatively much abbreviated; while the Part (II.) which treated of the phenomenal relations existing between the excited organs and mental phenomena, has been relatively somewhat expanded. Here considerable new material — especially in the chapter on "Consciousness, Memory, and Will" — has been added. I have thus aimed to furnish a complete and yet compact *text-book* for the briefer study of mental phenomena from the experimental and physiological point of view.

In carrying out the general aim of this manual, both pupil and teacher have been kept in view. The material has been arranged so as to adapt it for learning with the least unnecessary expenditure of strength and time. It is my hope also to have succeeded in providing those who give instruction with a book which can be successfully taught.

Some equipment of apparatus is desirable, if not absolutely indispensable, for the most effective instruction in physiological psychology. This equipment need not, however, be large or expensive. A set of models of the brain (I recommend the Bock-Steger), a few charts, a judicious selection of histological preparations, a machine for mixing color-sensations, etc., are of great assistance.

For the use of teachers, of more advanced or mature pupils, and of such readers, generally, as can command the patience and the time, the "Elements of Physiological Psychology" is still to be preferred. For most teachers who adopt the present, smaller treatise as a text-book in the class-room, the larger work will be found indispensable for their private use. The latter is still, in most of the subordinate topics, well abreast of the very latest researches.

And if its material is constantly supplemented by those notices of new discoveries for which one must look to periodical literature (*e.g.* the *American Journal of Psychology*), it will serve to keep even the teacher who is not a specialist in the lines of physiology and psycho-physics, in advance of his classes.

Having been for some years a teacher of this subject, I am well aware what are the difficulties of presenting it. But I have also learned that the rewards which follow the overcoming of those difficulties are correspondingly great. It will be a matter of great interest to me, therefore, to receive suggestions and encouragement from those of my fellow-teachers who may avail themselves of this book.

GEORGE TRUMBULL LADD.

YALE UNIVERSITY, NEW HAVEN,
Nov., 1890.

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PHYSIOLOGICAL PSYCHOLOGY.

INTRODUCTION.

NATURE OF PHYSIOLOGICAL PSYCHOLOGY.

THE satisfactory definition of any science is often one of the latest and most difficult achievements of that science. Our definition of the particular science which we intend to consider must, therefore, be understood as preliminary. It involves positions upon various disputed questions which the beginner is quite unable to comprehend; and it must be allowed, in a measure, to rely upon the course of the following investigation for its explanation and defence. Everything cannot be said at once. Terms must be freely used, the meaning of which will be made clear only by their use; and answers to later inquiries will sometimes be implied in what is said upon inquiries that are earliest raised.

It is plain that a correct conception of *Physiological Psychology* involves some special knowledge of those two sciences whose names are combined in the term itself. These are, of course, Psychology and Physiology. It is also plain that a peculiar relation is assumed to exist between certain of the results obtained by the study of these two sciences; otherwise they could not properly be combined in one term. It is furthermore suggested by this compound name, that the science which furnishes the noun — namely, psychology — defines the end which we desire to reach; while the science which furnishes the adjective — namely, physiology — prescribes the means which we are to employ. This suggestion we shall find to be confirmed by our subsequent investigations.

Definition of Pyschology. — It was for a long time customary to define psychology as "the science of the human soul." Sometimes the definition went so far as to add that the soul, "as the *real* foundation of the spiritual life," or as "the subjective spirit," is the "subject-matter of psychology." Of late, however, serious objections have been raised against every such definition. It has been complained that the word "soul," although its German equivalent is freely employed in biological and physiological treatises, cannot be sufficiently kept free, for scientific purposes, from theological and other prejudices. The word "mind," which had originally a much narrower significance, has therefore been substituted in the greater number of English works on psychology. Thus Mr. Sully defines psychology as "our general knowledge of mind reduced to an accurate and systematic form."

Other objections to the customary definition of psychology are not met, however, by exchanging the word "soul" for the word "mind." Thus it is said that both words are often used so as to conceal the unproved assumption that mind or soul is an independent entity; whereas it is the business of the science of psychology to prove, if it can, the existence of such an entity. Biology, which aims to extend its researches so as to include mental as well as other vital phenomena, sometimes asserts that it wishes the opportunity to explain what occurs in consciousness without making use of any assumptions. Some writers, then, have gone so far as to advocate "psychology without a soul." Others, on the contrary, have thought they found proof, in the complex phenomena of human life, of both an "animal" and a "rational" soul.

In order to the intelligent pursuit of physiological psychology, it is necessary to notice the foregoing objections only very briefly. Our view of the best preliminary description of the nature of psychology is as follows: It is expedient, as far as possible, to avoid all controversy at the beginning of our scientific investigation. We should therefore be willing, where this can be done, to dispense with controverted words in forming our fundamental conceptions. It is also more satisfactory, from the purely scientific point of view, to have the definition include only a description of that particular group of phenomena which it is the business of the science itself to explore. In this way, then, we define *psychology with reference to its primary problem*, which *is*, *the description and explanation of the states of human consciousness, as such.*

If the term "sentience" seems preferable to consciousness, it must be understood as equivalent to consciousness in the broader sense of the latter word. We may then say that psychology is the science which describes and explains the phenomena of the sentient life of man.

This definition plainly implies an acquaintance, already gained, with a certain class of phenomena. These are the phenomena of consciousness. What it is "to be conscious," and what is that peculiar character which belongs to all phenomena of consciousness, as such, can never be defined.

It would be inconvenient and unnecessary — not to say impossible — to refuse to speak of the "soul" or "mind" simply through fear of unscientifically making the assumption that some such entity really exists. In all languages, and in the every-day use of them all, men in expressing their states of consciousness, as well as in addressing their fellows, employ such terms as "I" or "me," and "thou" and "he," or "it." But all these words imply some kind of reference to a subject of the phenomena of consciousness; they also imply a contrast between this subject and other subjects to which other phenomena are attributed.

In all the earlier part of our investigation, whenever we use the word "mind" or "soul," we wish to imply no more than all men inevitably mean whenever they say "I" see, or think, or feel, or purpose, this or that. It is the seeing, thinking, feeling, and purposing, etc., as states of consciousness, with this possible reference to a subject of them all (*states of consciousness as subjective*), which constitute the field to be explored by psychology.

Definition of Physiology. — The science which is to be combined with psychology in our investigations is human physiology. This is the science of the functions of the human physical organism. Its modern study implies an acquaintance with several other sciences with which it is closely allied, or upon which it is dependent. These are molecular physics and chemistry, as related to the structure and changes of the tissues of plants and animals; biology, including the allied phenomena of plant life; embryology and the general theory of development; and gross and special microscopic anatomy, or histology. It is only, however, with a small part of this vast domain that physiological psychology has directly to deal. Its chief concern is with the structure and functions of the human nervous system.

Definition of Physiological Psychology. — It has already been implied that our conception of this science is dependent upon the way in which we understand the two sciences to be combined in its pursuit. But the science of psychology furnishes the end or final purpose of our researches. In other words, we aim to describe and explain the states of human consciousness, as such. On the other hand, physiology furnishes the peculiar means to be employed, — the point of view held in our description, and the method and source of our explanation. We study the subject-matter indicated by the noun; but we study it by use of the somewhat peculiar means and ways of approach indicated by the adjective. We may, then, define physiological psychology as *the science of the phenomena of human consciousness in their relations to the structure and functions of the nervous system.* It is psychology, because it is the science of the human mind, or soul; it is physiological psychology, because it regards the mind as standing in peculiar relations to the bodily mechanism.

Method of Physiological Psychology. — In its method this compound science necessarily partakes of the characteristics of the two sciences which enter into it. But these two sciences differ somewhat widely in respect to their long-established methods. They also differ in their very nature in such a way as to make necessary a difference of method in their pursuit. It has always been held by a great majority of its students that the method of psychology is necessarily what is known as "introspective." But there can be no doubt that the method of physiology is one of external observation and experiment; since physiology is a physical science and has to determine external facts of the structure, development, and functions of a physical mechanism. It is not strange, therefore, that doubts and even disputes have arisen as to the possibility of combining these two methods, and as to the proper way of making the combination, in case it is to be made at all. These doubts and disputes are, however, for the most part, unimportant.

The method to which psychology has, from time almost immemorial, appealed is, as has been said, *introspection*, or self-consciousness. The exhortation given to the student of mental phenomena is, accordingly, made to run as follows: "Would you know what it is to see, to hear, to think, to feel, to desire, to will? Then look within yourself and find the answer there." To answer such questions, inspect *within* (*intro*-spect); to know what is the meaning of consciousness, in any of its varied forms, be *self*-conscious, or aware of the states of consciousness as immediately known to be your own. But like the definition of psychology, this conception of its method has of late been much called in question, and its lack of scientific character as well as its general unfruitfulness have been exposed.

What view, then, shall we take of the use of introspection in psychology, and more particularly, in physiological psychology? Now there should be no mystery or arrogant assumption about such words as "science" and "scientific method." Science is knowledge — real, verifiable, systematic. Scientific method is nothing but the way of arriving at such knowledge. In physiological psychology, as a science, any way of arriving at genuine knowledge is justifiable; all ways of arriving at such knowledge should be diligently and skilfully employed. But the phenomena which we must somehow know, in order to describe and explain them, are states of consciousness; and states of consciousness, *as primary facts*, can be ascertained in no other way than in and by consciousness itself. This way of ascertaining these facts is introspection. Introspection is, therefore, not only a legitimate but it is an indispensable method of physiological psychology. To object to it, so far forth, is not only inexpedient and useless, but is even absurd.

Psychology as a *science*, however, requires not only that we should ascertain by introspection what the states of consciousness, as primary facts, actually are, but also that we should explain these facts and their relations to one another in the life of the mind. Such explanation requires at least two things: these are, the analysis of the states into their simplest factors, and the discovery of the laws under which the states are related to each other and to all the conditions on which they depend. Our adult states of consciousness furnish the problems to psychology; they are its primary facts, the admitted data from which it takes its start. But they are all, as states, exceedingly complex, and involve numerous factors. Self-consciousness can no more discover all the factors which have united to form these states than simple external observation can analyze a portion of water into its constituent oxygen and hydrogen gases. Especially is it true that few of the antecedent and accompanying conditions of these complex states of consciousness can be discovered by introspection. Introspection, therefore, can never serve as the sole method for establishing a science of psychology.

Moreover, those antecedent or accompanying conditions of the states of consciousness, which physiological psychology particularly endeavors to discover, are the structure and functions of the nervous system. About these matters introspection can, as a rule, tell us nothing whatever. The physical science of physiology, with its method of external observation and experiment, must be relied upon to describe such conditions of mental phenomena.

It is obvious, then, how physiological psychology must combine the two methods which belong to the two sciences on which it depends. Introspective psychology must furnish us with the description of those complex states of consciousness, as such, which it is desired to explain. These furnish the problems to be solved. Physiology, on the other hand, must be relied upon for a description of the living and active nervous system, regarded as giving conditions to the origin and character of the states of consciousness. Physiological psychology, therefore, attempts to bring the two orders of phenomena, those called mental and those belonging to the nervous system, face to face. It considers them as mutually related; it endeavors, as far as possible, to unite them in terms of a uniform character, under law. Its method is to explain the phenomena of man's sentient life as correlated with the life and growth and action, under stimuli, of his nervous system.

Divisions of the Subject. — The different chapters of this book fall under three main divisions. We shall first consider the structure and functions of the nervous system from the modern mechanical point of view. In these earlier chapters we must rely upon the method of external observation and experiment as employed by the modern science of psychology. Our object will be to give a clear picture in outlines of what the nervous system of man is, and of how it acts in response to the different forms of stimuli which excite or irritate it. This work requires little reference to states of consciousness or to the nature of the mind. We shall, in the main, consider the nervous system as a purely physical mechanism. Yet even in these chapters certain important considerations bearing upon the nature of the mind and its relations to its bodily basis will indirectly come into view.

The next eleven chapters (VIII.–XVIII.) may be considered as constituting the second or main division of the book. In these chapters the various relations which the science of physiological psychology has discovered between the states of conscious mind and the conditions of the excited nervous system, are presented in order. Such relations may conveniently be considered under three general groups or classes. The first group comprises the relations which can be established between the condition and activity of the higher nervous centres and the phenomena of conscious sensation and motion. The principal question raised under this head concerns the so-called "localization of function" in the hemispheres of the brain. The second group of relations includes the phenomena with which *psycho-physics* (in the more precise use of the term) attempts to deal. Such are the relations which exist between the quality, quantity, combination, and time-order of the various stimuli which irritate the nervous system, and the kind, amount, composite result, and time-relations of the mental phenomena. A third class of relations considers mind and body as dependent upon differences of age, sex, race, etc.

At the close of the more strictly scientific discussions of the book, we shall be in position to verify certain conclusions as to the nature of the human mind, and as to its general connection with the bodily organism. Some of the considerations introduced at this point will be of the kind ordinarily known as "metaphysical." We consider it scientific to postpone these questions, as well as all assumptions bearing upon them, until we have candidly and thoroughly discussed the related phenomena and the laws (or uniform ways) of their relation. But we also hold that psychology, even when it employs the physiological method, has the right, and is under obligation, to suggest and defend true conclusions as to the nature of the mind.

Benefits of the Study. — It has been shown that physiological psychology can scarcely claim to be an independent science, or even a separate and definite branch of general psychology. It is, nevertheless, a most interesting, suggestive, and productive way of studying mental phenomena. For a long time the so-called "old psychology," as pursued by the introspective and metaphysical methods, made little or no advance. In a single generation, as pursued by the experimental and physiological methods, the science of psychology has been largely reconstructed.

The modern science of man emphasizes the necessity of studying his nature and development as that of a living unity. Man is known as the head of a series of physical and psychical existences. Only by considering him in this way can we have a trustworthy and adequate picture of his mental life and mental evolution. Such a consideration the psychology which relies *solely* upon introspection and metaphysical speculation is unable to furnish. The actual achievements of the new science of physiological psychology — though, of course, still including many uncertainties and leaving many gaps to be filled — are a sufficient justification of its demands upon all students of the human mind. Further proof of the benefits of its study we confidently leave to the test of the student's experience.

CHAPTER I.

SUBSTANCE OF THE NERVOUS SYSTEM.

CHEMISTRY and the microscope have succeeded fairly well in analyzing the substance of the human nervous system. For this purpose it is safe, within certain limits, to direct our observation and experiment upon the lower animals, and to draw inferences from them which will apply to the case of man. The chemical constituents and minute structure of the *elements* which compose all nervous substance are largely the same. In describing these matters, it is not, then, so necessary to pay strict attention to the specific animal form from which the substance is derived. It is the way in which the elements are combined into organs, and the development and elaboration of function as dependent upon these organs, which constitute the marked differences between the nervous system of man and that of the lower animals.

The elements which enter into the nervous substance require to be considered in three ways: (1) as respects their chemical constitution; (2) as respects their form or structure; (3) as respects their general physiological function. For purposes of convenience and orderly arrangement we reserve the third consideration for another chapter.

CHEMISTRY OF THE NERVOUS SUBSTANCE.

There are few perfectly certain facts which can be obtained from the science of physiological chemistry, respecting the constitution of nervous matter. These facts are suggestive and valuable, though their bearing on a theory of nerve-function is not always clear. The necessary chemical analysis is encompassed with many special difficulties. Nervous substance is a product of life, and living tissue cannot be at the same time preserved in normal condition and subjected to the treatment of the laboratory. Even when we succeed in determining the constituents which compose it, their *constitution* — their normal chemical arrangement and behavior — cannot easily be preserved. It is impossible, for example, to determine the specific gravity of uncoagulated blood, "except by operating with extreme expedition, and at temperatures below 0° C."

Kinds of Nervous Matter. — There are two kinds of nervous matter, — white, or fibrous, and gray, or vesicular. These differ in color, microscopic structure, specific gravity, and chemical constitution. The specific gravity of the gray matter in man is given as 1.029–1.038; that of the white matter, as 1.036–1.043. The lighter weight of the gray nervous substance is due to the fact that it contains relatively more of water and less of solids. The percentage of water and of solids may be approximately given as follows: of the gray, 81.60 and 18.40; of the white, 68.35 and 31.65. The amount of water in both kinds of nervous substance differs with age, sex, and in different regions of the spinal cord and brain. It is larger in the young animal than in the adult, larger in the brain than in the spinal cord. These facts are doubtless connected with the degree of susceptibility to new impressions, and with the ease with which changes in habits are effected, both in the nervous substances, and, as connected with it, in the mind.

Non-phosphorized Bodies. — Of the solids composing the nervous substance, more than one-half in the gray and about one-quarter in the white consist of certain proteid or albuminous bodies. Such bodies are the only ones never absent from the active living cells; they exist in all vegetable and animal organisms. Very little is known of the peculiar chemical constitution which these proteid bodies take in the nerve-centres. They may be said to represent there the presence of that general matter of life which is the physical substratum of all vital phenomena.

Three other non-phosphorized bodies are found in the nervous tissues; these are called Cholesterin, Neurokeratin, and, more doubtfully, Cerebrin. *Cholesterin* is abundant, especially as a constituent of the white matter of the cerebro-spinal axis and of the nerves. It is supposed to exist, preformed, in the brain. It is described as a "monad alcohol," crystallizing in beautiful white crystals. Its formula has been given as $C_{26}H_{44}O+H_2O$. *Neurokeratin* may be derived from the medullated nerve-fibres and the gray matter of the nervous centres; it is not found in the non-medullated nerve-fibres. It contains nitrogen and a small percentage of sulphur. *Cerebrin* was announced by Müller, in 1858, as a nitrogenous body to be obtained from a precipitate of the brain. The existence of this substance preformed in the brain has, however, been disputed, although some of the chemists who dispute its existence admit the existence of a body "for which we may retain the name of 'cerebrin.'" The significance of these bodies for the mental life is not apparent, except so far as the fact is suggestive that they are all of a very highly complex chemical character. Of the meaning of this fact we shall speak further on.

The Phosphorized Fats.—The most significant constituents of the substance of the nerve-centres, from the point of view both of chemistry and of physiological psychology, are certain complex phosphorized fats. These bodies are highly characteristic of the centres of the nervous system. They are therefore of special interest to the student of physiological psychology. There are in particular three substances about the chemical constitution of which much dispute has arisen, but which belong in this class. They are called Protagon, Lecithin, and (more doubtfully again) Cerebrin. *Protagon* was discovered in 1864, and announced as a new proximate principle that can be separated from the brain, in a paper read in 1865 (by Dr. Oscar Liebreich). Its name signifies that he considered it to "lead the van." It is a very elaborate compound. Its formula has been given as $C_{116}H_{241}N_4O_{22}P$; or, more recently, as $C_{160}H_{308}N_5PO_{35}$. In spite of denials and disputes, subsequent very careful researches seem to make good the claim of protagon to be the best established "phosphorized proximate principle of the brain." In calling it a "proximate principle," it is of course assumed that it exists preformed in the brain, and is not the result of the somewhat elaborate process which is necessary to obtain it.

Lecithin is an organic compound which exists in large quantities in ova, spermatozoa, etc., as well as in the nervous tissues. It is supposed by some to be only one of a similar group of bodies which possess a higher percentage of phosphorus than protagon, and is, perhaps, formed from protagon by the addition of the needed phosphorus. We might then speak of "the lecithins" as a class of highly phosphorized compounds.

If we regard — and this seems most probable — protagon as the definite proximate principle among the phosphorized fats of the brain, *cerebrin* becomes one of those bodies that are of ill-defined properties, and doubtful claim to existence as proximate principles.

It is not necessary to speak in particular of other products which are found by laboratory treatment of the nervous substance, and which are perhaps to be regarded as products of the decomposition of protagon and lecithin.

Extractive and Inorganic Matters. — Certain extractive matters, such as creatin, xanthin, and lactic acids, which are found especially in the muscles, are also found sparingly in the brain. A very small amount — varying from 0.1 to 1 per cent. — of inorganic matters, such as alkaline phosphates and sulphates, chalk, magnesia, oxide of iron, etc., also exists in the brain.

Specific Chemistry of the Elements. — The more minute chemistry of the nerve-cells tells us simply that they are in the main protoplasmic and therefore rich in albuminous bodies. Since the gray matter is much poorer in complex phosphorized constituents, we conclude that the cells, which enter into this matter, are also poor in the same constituents. The different parts in the structure of the nerve-fibres seem to differ in chemical constitution. Their membranous envelope, like that of the muscles, yields gelatin on being boiled. The axis-cylinder is a mixture of albuminous and complex fat-like bodies. The chemical constitution of the nervous elements of the retina of the eye is very closely related to the phenomena of sight; for this sense is thought to be dependent upon the production, by the stimulus, of photo-chemical changes in these elements. The retina seems, accordingly, to contain the same bodies as the central nervous system. Even the two segments into which the rods and cones of the retina break up exhibit marked differences in their chemical, as well as optical characteristics.

Chemistry of the Functions of the Nerve-Elements. — Like every other natural material structure, the nervous system is obviously adapted to a peculiar kind of work. Chemically considered, it has two very important characteristics: its constitution is extremely complex, and the compounds that enter into it are highly unstable. It is evident, then, that it contains, *stored*, *a large amount of* disposable *energy;* and, also, that it *readily yields this energy*, whenever the equilibrium of its molecules is even slightly disturbed. But a more remarkable thing about it is, that — as we shall see later on — it explodes, as it were, with increasing surrender of its energy as the number and intensity of the demands upon it are increased. Within certain limits, it behaves very much as would a convenient kind of gun, which should be so arranged as to go off with greater energy, as the pressure of one's finger on the trigger were repeated or increased.

More wonderful still, — the nervous substance may be said to make its own powder as fast (within certain limits) as it is burned. It is itself the seat of a chemical synthesis, which results in constructing the peculiar bodies just described, from the material furnished by the blood. Such bodies have a high value as combustibles; for — as has been said — they hold in store a large amount of easily disposable energy. Yet further, the nerves, as distinguished from the nerve-centres and the end-organs of sense, can act repeatedly in quick succession with undiminished force. It would seem, then, that they must have the power of recombining immediately the molecules which have been thrown down from their condition of a highly complex compound having an unstable equilibrium. Nerves appear to be so constituted chemically, that they can serve as laboratories to retain the constituents of their own substance and to reform them as fast as they are dissolved.

It is therefore impossible not to regard the substance of the nervous system as especially fitted by its chemical constitution to serve the purpose which it actually performs. It is so constituted as to be in a high degree susceptible to the slightest attacks from various kinds of stimuli. It acts and recovers, and propagates the changes set up in any part of it, with a high degree of rapidity. It stores in compact form a large amount of easily disposable energy. It is precisely such a system of physical bodies as this, which is fitted to be especially correlated with the phenomena of conscious sensation and motion.

STRUCTURE OF THE NERVOUS ELEMENTS.

From the science of chemistry we now turn to the science of microscopic anatomy or histology, and inquire what it can tell us with respect to the structural form of the nervous elements. If we analyze with a microscope a section of the nervous matter of the central organs, its apparently homogeneous character breaks up into three or four kinds of substances. Of these one at least is not generally considered to have a nervous character.

Neuroglia. — A diffuse, finely granular substance, called "neuroglia" or "nerve-cement" exists in quantities large enough to form an essential part of some localities of the brain and spinal cord. It appears on examination to be a delicate net-work, in which certain small cells (called "neuroglia cells"), supposed to belong to the sustentacular tissue, and other more conspicuous cells, usually of a stellate shape, are found. It is not always clear to what its appearance of granular or molecular matter is due. The office of the neuroglia is supposed to be — as the name signifies — the holding in place of the true nerve-elements by filling in the gaps between them. It is therefore classed with the connective, or sustentacular, rather than the nervous tissue; although it forms a constituent of the nervous substance in the great nerve-centres.

Nerve-corpuscles. — Very minute bodies, scarcely more than from $\frac{1}{2500}$ to $\frac{1}{5000}$ of an inch in diameter, and consisting either of naked nuclei or of nuclei with only a small amount of surrounding protoplasm, are found abundantly in the gray matter of certain of the nervous centres. Some of them, like the typical nerve-cells, give off processes. They vary much in shape, — are multipolar, bipolar, or unipolar. Some of them so closely resemble the more highly developed nerve-cells called "ganglionic" that they have been described as "nuclei invested by only a small quantity of cell-substance." It is probably not possible to draw any fixed line through this class of minute bodies, or to separate the more highly developed members of the class from the larger and more elaborate bodies to which the name of "nerve-cells" is unhesitatingly given. They may therefore be regarded as *nerve-corpuscles* in various stages of development, from mere granules to ganglionic cells.

The undoubtedly nervous elements of the substance of the nervous system are of two kinds, as respects their structural form: these are nerve-fibres and nerve-cells. The white matter of the peripheral nerves and of the nerve-centres is composed of *nerve-fibres*. The gray matter of the nerve-centres contains, besides the nerve-fibres, numerous *nerve-cells*. Both these elements require then a more detailed description.

NERVES, NERVE-FIBRES AND THEIR FIBRILS.

Nerves. — What is ordinarily called a "nerve" appears to the naked eye as a cord of a whitish or grayish color and uniform structure. On examination, however, we find that it consists of several bundles (or "fascicles"), of various sizes, bound together by connective tissue. When followed toward the surface of the body, it divides and subdivides, until its subdivisions consist of a single nervous element called a *nerve-fibre*. The bundles of the nerve are enclosed in a special sheath (called *neurilemma* or *perineurium*). As the nerve-fibres run toward the central organs they are, as has been indicated, bound together to form a nerve-fascicle. A small amount of connective tissue appears between the several fibres within the same sheath. The character of the sheath itself is changed and it becomes attached to surrounding structures by a layer of connective tissue.

Kinds of Nerve-fibres. — The nerve-fibres which compose those nerves that run from the central organs to the peripheral parts of vertebrate animals, are divided into two classes. These are called *medullated nerve-fibres*, or nerve-tubes, and non-medullated nerve-fibres, or *fibres of Remak.*

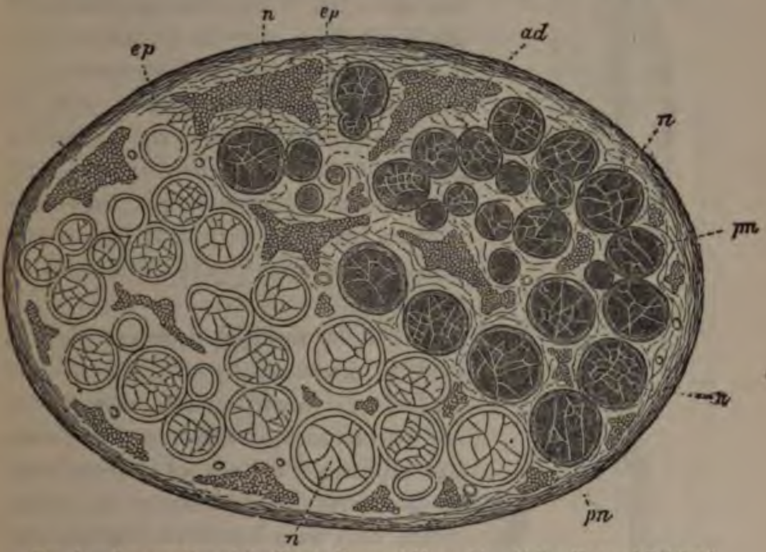

FIG. 1.—Cross-section of the Sciatic Nerve of Man. $^{8}/_{1}$. (After Key and Retzius.) The left lower half is schematic. *n*, *n*, Bundles of nerve-fibres, surrounded by *pn*, *pn*, the perineurium: between them appears the connective tissue, epineurium (*ep*, *ep*), and adipose substance (*ad*).

The former belong particularly to the brain and spinal cord; they are found only in vertebrate animals. The latter belong particularly to the sympathetic system. This distinction, which is easy to make for the peripheral nerves, becomes difficult or impossible when we attempt to carry it out within the more complex nerve-matter of the central organs.

Within the nerve-centres of the brain and spinal cord there appears, at first sight, to be a considerable variety of nerve-fibres. Here we find very fine nerve-threads which require an enlargement of five hundred or more diameters to make them even visible. Certain very delicate transparent lines, differing from the foregoing by their larger size and fibrillar structure, also appear. These are the so-called "naked axis-cylinders." Both of these may be invested with a medullary sheath and so converted into medullated nerve-fibres. Or, in the peripheral nerves, they may be found without such a sheath. And whether medullated or not, they may become invested with a delicate covering membrane (called "sheath of Schwann").

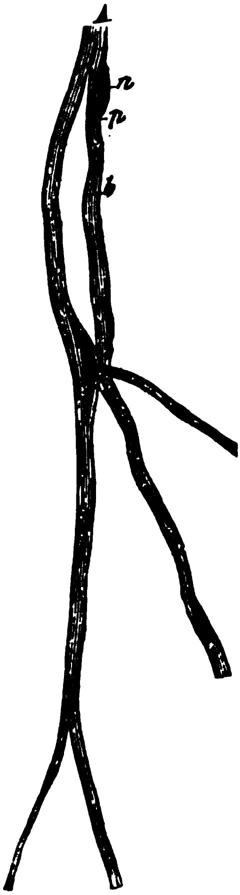

FIG. 2. — Fibres of Remak from the Pneumogastric of the Dog. $^{400}/_{1}$. (Ranvier.) *n*, Nucleus with surrounding protoplasm, *p*; *b*, striæ corresponding to fibrils.

It will be noticed, however, that it is the presence or absence of the *medullary sheath* which constitutes the one important difference between the different classes of nerve-fibres. It is therefore customary to distinguish only two kinds of nerve-fibres, according as they have, or have not, this covering of medullary substance.

Fibres of Remak. — These nerve-fibres are distinguished chiefly by the absence of the medullary sheath. They are grayish and translucent, with flattened nuclei lying at frequent intervals along their surface. When gathered into bundles, within the sheath of neurilemma, they are not placed side by side. They are rather, as it were, formed within the interior of the nerve, where they unite and divide so as to form an intricate net-work of fibres. When grouped into still larger bundles, or nerves, they are sometimes alone, but are more frequently connected with the medullated fibres.

Medullated Nerve-fibres. — By carefully teasing a nerve with fine needles we may separate its fibres for microscopic examination. While still fresh, certain of the fibres appear with a central part and a border on each side, like a translucent liquid in a *tube* of translucent walls.

By using different staining solutions, which act differently upon the different parts of its structure, the three-fold character of the medullated nerve-fibre is demonstrated. We thus distinguish: (1) An outer membrane, extremely thin, pellucid, and having nuclei, called the "sheath of Schwann"; (2) an interior layer of dimly granular, white, and highly refracting substance, semi-liquid during life, and called the "medullary sheath"; and (3) a cylindrical band of transparent albuminous material, called the "axis-cylinder."

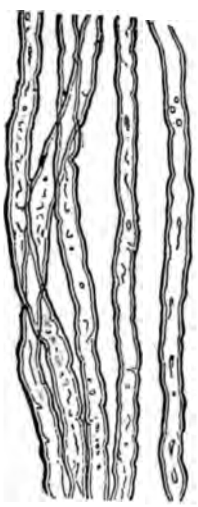

FIG. 3. — Medullated Nerve-fibres, with double and irregular contour showing. (Schwalbe.)

Since many nerve-fibres, although they are only naked axis-cylinders, perform truly nervous functions, we conclude that this interior portion of the nerve-tube is alone essential to its nervous character. The sheaths may then be regarded as *insulators*.

Besides its three-fold longitudinal character, modifications in the structure of the nerve-fibre occur along its length. Of these, two are most important. Places of constriction appear at certain points, situated beneath the outer sheath; these constrictions are made at the expense of the medullary sheath. They are called annular constrictions, or *nodes of Ranvier*. The portion of the nerve-

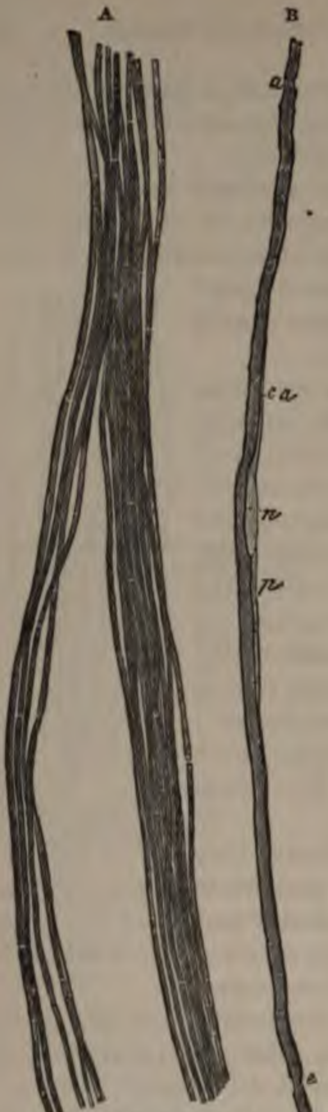

FIG. 4.—A, Medullated Nerve-fibres from the Sciatic of a Rabbit, stained with osmic acid, and dissociated in water. (Ranvier.)

B, Single Fibre Enlarged $^{400}/_{1}$. *a, a*, Annular constrictions, or nodes of Ranvier, nearly midway between which is *n*, the nucleus, with protoplasm, *p*, surrounding it; *ca*, axis-cylinder.

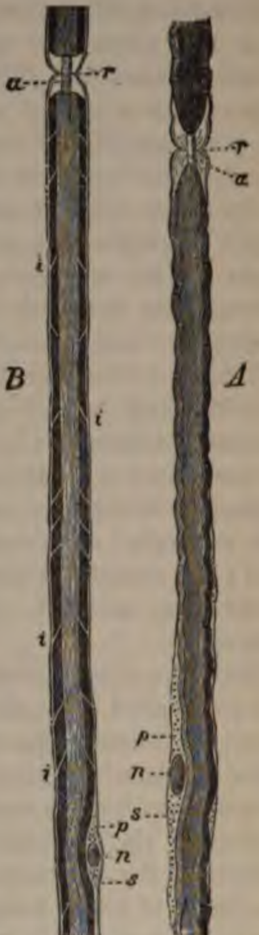

FIG. 5.—Medullated Nerve-fibres. (Schwalbe.) *a*, Axis-cylinder; *s*, sheath of Schwann; *n*, nucleus; *p, p*, granular substance at the poles of the nucleus; *r, r*, Ranvier's nodes, where the medullary sheath is interrupted and the axis-cylinder appears; *i, i*, incisures of Schmidt.

fibre included between two of them is called an "interannular segment."

Each segment of a nerve-fibre has a flattened elliptical *nucleus*, generally about half-way between the two nodes which bound the segment. This nucleus sometimes comprises within it a still smaller nucleus (nucleolus). Between the nucleus and the medullary substance there exists a minute mass of protoplasm.

Other small irregularities of structure, which the medullated nerve-tubes exhibit under the higher powers of the microscope, it is not necessary to describe (see, however, Fig. 5).

Fibrils of the Axis-cylinder. — A discussion has been going on for some forty or fifty years as to the meaning of certain yet more minute divisions which appear, under the very highest powers of the microscope, in the structure of the axis-cylinder of medullated nerve-fibres. Some investigators claim that fibrils can be distinctly traced (as see Fig. 6) in living nerve-fibres, where they are in process of forming and are still naked, or where they are seen just issuing from nerve-cells. These fibrils they regard as the ultimate "nerve-lines" — swimming or suspended, as it were, in a semi-fluid medium — along which the nerve-processes run. But others regard the substance, in which these "primitive" fibrils appear suspended, as the real nervous substance; and they describe it as diffused in the cavities of a sponge-like network.

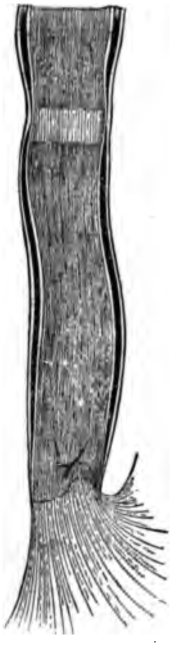

FIG. 6. — Fibrillated appearance of the Axis-cylinders of Medullated Nerve-fibres. (Hans Schultze.)

Whichever of the foregoing views is taken, it would seem that the structure of even the axis-cylinder is not homogeneous; but that it contains provision for parallel or interlacing lines of nerve-action, running along within the delicate covering of cells which forms its limit. So marvellously minute and complicated are even the so-called elements of this nervous mechanism!

Size of Nerve-fibres. — As a rule, the non-medullated nerve-fibres are smaller than the medullated, — the former being from $\frac{1}{6000}$ to $\frac{1}{3000}$ of an inch in diameter, and the latter from $\frac{1}{1500}$ to $\frac{1}{2000}$. But this rule is not always followed. In the white matter of the spinal cord the medullated fibres vary in size from $\frac{1}{1200}$ to $\frac{1}{2000}$ of an inch; but near the gray matter of the cord, they are sometimes not more than $\frac{1}{7000}$ of an inch. The fibres are much finer in the gray matter of the cord and brain ($\frac{1}{7000}$ to $\frac{1}{14000}$ of an inch in diameter); they are finest of all in the superficial layers of the brain, or in the nerves of special sense. In some instances the axis-cylinder may be not more than $\frac{1}{100000}$ of an inch in diameter.

GANGLIONIC NERVE-CELLS.

The undoubtedly nervous cells vary greatly in size and shape, but when subjected to the microscope they all exhibit certain common characteristics.

Ganglion-cells. — These nerve-corpuscles may be described as irregular masses of protoplasm, finely granular and delicately striated, with a large nucleus which is well defined and vesicular in appearance, and usually contains a shining nucleolus. They send off one or more processes. In shape, some are nearly round; others are egg-shaped, caudate, stellate, or like a flask or the blade of a paddle; still others resemble the foot of an animal with claws. In size they vary from about $\frac{1}{250}$ to $\frac{1}{3500}$ of an inch.

To a certain extent, the shape and size of the nerve-cells are characteristic of the part of the central nervous system where they are found. For example, large cells of irregular shape with branching processes are found in the "motor" regions of the spinal cord. Cells very similar to these seem also to be present in certain "motor" regions of the brain. Pyramidal cells are characteristic of the cortex, or gray rind, of the brain; and a peculiar layer of irregular globular cells is found just at the inner edge of the gray matter of the cerebellum. The most recent researches indicate the possibility of distinguishing the sensory from the motor cells in the cortex of the brain. The former are thought by some observers to be smaller in size, flask-shaped or balloon-shaped, and less susceptible to staining. In the same regions the motor type is thought to be pyramidal.

The Ganglionic Globe. — The higher powers of the microscope reveal the bewildering complexity of the structure of the fully developed nerve-cell. But regarding its details there is still uncertainty and dispute. The bipolar ganglion-cell of the fish has usually been considered as a common type. This cell has two parts: (1) A covering, which is described as "fibrillary"; and (2) a globe composed of granular substance and containing near its surface a nucleus with one or more nucleoli. A recent description from this point of view makes the nerve-cell consist, not only of a nucleus, but also of a "dense tangle" of extremely minute fibrils with an irregularly granular material filling the spaces between them.

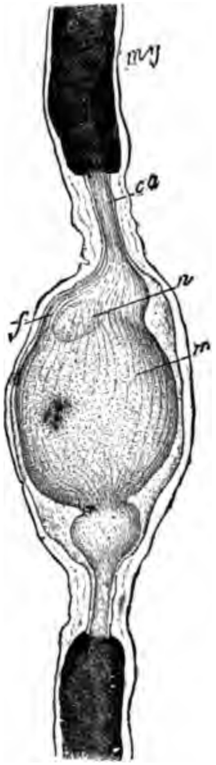

FIG. 7.—Nerve-cell from the Spinal Ganglion of the Ray. $^{350}/_{1}$. (Ranvier.) *my*, Medullary sheath of nerve-fibre, enclosing *ca*, the axis-cylinder, the fibrils of which (*f*) separate and run over the ganglionic globe, *m*; *n*, nucleus.

Others regard the "fibrillary" or "striated" appearance of the cell as indicating that the exceedingly small ("primitive") nerve-tubules, of which it mainly consists, are suspended, as it were, in a spongy network within the cell-body.

Processes of the Ganglion-cells. — It is generally agreed that two kinds of processes are given out by certain of the nerve-cells; but the character and fate of these processes are still in dispute. Deiters and others describe the case — and their account has until recently been the accepted one — in the following way: Ordinarily, only one of the processes of the nerve-cell becomes continuous with the axis-cylinder of a nerve-fibre. This process is therefore called the "axis-cylinder process." It can often be distinctly seen to be fibrillated; its fibrils are continuous with those of the axis-cylinder of the nerve-fibre. The other processes, also, have fibrils, but they are not continuous with those of any nerve-fibre. These latter processes are sometimes called "branching," since their fibrils ramify, separate, and unite again, and finally become lost in an intricate network of extremely minute nervous filaments.

Others, whose investigations are more recent (Golgi, Forel, Kölliker), maintain that the axis-cylinder process is always found to be branched. In some cases the axis-cylinder maintains its identity, but gives off many fine lateral branches. In others, the branching is more profuse and rapid, and the axis-cylinder soon loses its identity. These investigators also deny that the so-called "branching processes," which do not become continuous with axis-cylinders, communicate with each other; they do not "anastomose."

CONNECTION OF THE NERVE-FIBRES AND NERVE-CELLS.

Few subjects of microscopic anatomy are more baffling, and at the same time more interesting and important, than the exact determination of the physical connection between the two principal elements of the nervous substance. On the one hand, it has been held that no connection between nerve-cells and nerve-fibres can ever certainly be made out, and that even its existence is doubtful (*e.g.* by Wyman, in 1852). Next, a direct connection is thought to be made out in certain instances and assumed to hold good as a rule (*e.g.* by Vulpian, in 1866). Then we have the definite theory, said to be "established," that for every nerve-cell there is a corresponding nerve-fibre which is continuous with its one "axis-cylinder process." Thus the ganglionic nerve-cell is assumed to be "the one perfectly definite type" of all the seemingly different nerve-elements. Nerve-fibres are, accordingly, described as nerve-cells drawn out into a long process which serves to connect them with other similar cells and fibres, or perhaps with the muscular fibres which the nervous substance commands. On the other hand, the more careful recent researches seem to indicate that the relations between the separate elements of the nervous substance are much more intricate and often indirect than this captivating theory would lead us to suppose.

In the midst of such contradictory evidence from the experts themselves, we may content ourselves with stating the views of the more recent investigators. For in the use of the higher powers of the microscope only what is *recent* is of much value. The more recent views maintain that rarely, if ever, does a direct origin of the nerve-tubes from the nerve-cells take place. The slender fibrils of the central nervous substance come, partly, from the breaking up of the processes of the nerve-cells; they come also, partly, from nerve-tubes that run across from one portion of this substance to another, or run into it from the periphery of the nervous system. It is in this "fibrillar mass," which must be regarded as interposed between them and the nerve-cells, that the nerve-tubes have their origin. In other words, *the connection between nerve-cells and nerve-fibres of the peripheral nerves is ordinarily indirect.*

The attempt has been made to procure additional evidence on this subject by counting the nervous elements of both kinds in the ganglia and roots of the same sections of the spinal cord. But this method gives conflicting results. One investigator (E. A. Birge) finds that his count makes the number of fibres and cells so nearly alike (*e.g.* in ten motor roots 5734 fibres and 5777 cells) as to give countenance to the theory, that each fibre has a special direct connection with a single cell. Other investigators, however, find their count favoring the view that, in the roots of the spinal cord, two cells, as a rule, unite their processes to make up the axis-cylinder of a single nerve-fibre. Some observers claim to have seen through the microscope cases of such a union.

It must be admitted, therefore, that the exact manner of the connection between the nerve-cells and the nerve-fibres is not, as yet, determined. The evidence goes to show, however, that it is very largely indirect. But possibly both kinds of connection — namely, the direct and the indirect — may be at some time established to the satisfaction of all parties. It may then, also, be possible to tell what is the meaning, as respects the function of the nervous elements, of these two kinds of connection. And, indeed, some very careful observers have already advanced the theory, that the connection is direct in the case of the motor nerve-tubes, and indirect in the case of the sensory nerve-tubes. But this theory has at present no sufficient evidence.

CONCLUSIONS FROM THE STRUCTURE OF THE NERVE-ELEMENTS.

In spite of all doubts respecting many and important details of the structural character of the nervous substance, the general bearing of what *is* known is evident enough. The entire nervous system of man is compounded of a very few kinds of nerve-elements, put together into a great variety of organs, whose structure and functions the subsequent chapters will explain. Here then is a wonderful unity composed of an almost infinite complexity. The nerve-elements are essentially the same in all the organs of man's nervous system. The same kind of molecular disturbance, called "nerve-commotion" or nervous "impulse," may be supposed to be producible and capable of propagation in them all. But even these elements are so indescribably fine in their structure, and are probably connected to form the *system* in such an infinite number of slightly different ways, that this nerve-commotion can be indefinitely varied as to its shading, intensity, and extent and paths of distribution.

Especially do we notice that the elements of the nervous system are fitted to form "tracts" along which the nerve-commotion may run. Every nerve-fibre constitutes one such tract, — capable, it would seem, of subdividing at either end into a considerable number of fibrils or subordinate tracts. The nerve-cells, too, seem fitted to serve as tracts for the propagation, and perhaps also as centres for the distribution and modification ("shunting places" they have sometimes been called) of the same nerve-commotion. The processes which they give off — whether directly or only indirectly, or both, does not concern our present purpose to determine — serve to bring them into connection with other nerve-elements of the same kind; and through the peripheral nerves, with the muscles and special organs of sense. Both kinds of nerve-elements are certainly adapted to serve the purpose of "conductivity" in an exceedingly complex system of interrelated organs.

Among the organs of the nervous system, moreover, we shall find prominent the so-called "end-organs of sense." Of course, the importance of these organs for the life of the mind needs no defence. But the organs of sense, in so far as they are nervous in character and so capable of serving the purposes of a life of conscious sensation, are constructed by combining the same two nerve-elements, — namely, the nerve-fibres and the modified nerve-cells. The "irritability" of the nerve-elements is therefore an indispensable thing. As a matter of function, it is provided for in their very structure. They are so made, so delicate and so sensitive, that the slightest amount of the appropriate kind of stimulus, furnished by external nature, stirs them to nervous action.

In a still more wonderful manner do we find that these elements, when combined into the central organs of the brain, are irritable in correlation with all the changing phases of the mind. For this reason, among others, we may be inclined to maintain, that no other mechanism in nature is so surprisingly fitted for the most important relations as that which is made by combining the nervous elements. As a *system*, this mechanism depends, for what it is and for what it can do, upon the structure, chemical and microscopic, of the nerve-corpuscles and nerve-fibres of which it is composed.

CHAPTER II.

STRUCTURE OF THE SPINAL CORD AND BRAIN.

THE nervous elements, whose chemical constitution and formal structure were described in the last chapter, are combined into a great variety of "organs"; and these organs are systematically arranged, in relation to each other, for the accomplishment of a common work. This arrangement of organs, all of which are made by combining the nerve-fibres and nerve-corpuscles in their "bedding" of connective tissue, is called — significantly — the "Nervous System." It is the mutual condition and reciprocal action of the elements which give its peculiarities to this mechanism.

It will greatly assist our understanding of the nervous system if we, from the first, regard it in the light of an appropriate idea. Such an idea is secured when we consider the whole as a natural development in response, as it were, to a problem requiring a mechanical solution. This idea may be presented more clearly by considering how a similar but much simpler problem is solved by an amœba. The amœba, under the microscope, appears wholly, or almost wholly, structureless. But it is, of course, composed of a great number of molecular elements which are undergoing constant change. It is alive; its substance is therefore (1) metabolic, (2) respiratory, (3) reproductive. But more important still for our purpose is the fact that the amœba is (4) irritable and (5) automatic. When it is acted on by stimuli from without, it suffers an explosion of energy which generally results in its changing its form and place. Some of its movements seem rather due to unknown internal changes, and are therefore called "automatic." Thus does the amœba solve its problem of adjusting itself to its changing environment.

Let now the problem become much more complicated, and the mechanism employed for its solution correspondingly complex. The metabolic, respiratory, and reproductive functions of the animal will each have separate systems of organs assigned to their use. A system of muscles will be formed which will possess in an eminent degree the "amœboid contractility." But the property of being irritable and automatic will become the special endowment of the nervous system.

A greater differentiation of organs and functions of organs must take place as the problem of the life of the animal becomes more complex. Certain groups of cells must become more eminently irritable or susceptible to external stimuli; certain others more eminently automatic or susceptible to internal stimuli. But if all the groups of cells are to be connected into one *system*, strands of irritable protoplasm must be stretched between them, — thus binding them together into a community of action. Still further: it is obviously necessary that the muscular system, upon which the separate movement of the different masses of the animal's body, or of its whole body at once, depends, shall be connected with both the external and the internal groups of cells. Only in this way can the various forces of nature reflexly influence its movements, designed — as they are — to keep it adjusted to its changing environment; only in this way also can the animal exercise any "will of its own."

The most highly developed nervous system will, then, consist of the following necessary parts: (*A*) End-organs of Sense, like the skin, the eye, the ear, etc.; (*A′*) End-organs of Motion, like the attachments which the nerves have to the muscles; (*B*) Central Organs, like the peripheral ganglia, the spinal cord and the brain, — in which may come to exist (*b*) certain regions more distinctively motor, and (*b'*) others more distinctively sensory, and (*b''*) perhaps still others more particularly intellectual; and finally, (*C*) Conducting Nerves, which will be either (*c*) afferent and sensory, or (*c'*) efferent and motor.

Now the nerve-elements in man are actually combined into these various classes of organs — namely, end-organs of sense and motion, central organs, and conducting nerves — to make a nervous system. To accomplish this, the nerve-fibres are bound into bundles, called "nerves," in the manner already described (p. 18). The nerve-cells are grouped into masses of nervous matter, called ganglia, or gathered into larger bodies; and these are intersected with minute ramifications of the nerves, and interspersed with the finely granular substance called neuroglia. Of these masses or larger bodies, together with the nerve-cords which connect them, two so-called systems are formed. These are called the "Sympathetic System" and the "Cerebro-spinal System."

THE SYMPATHETIC NERVOUS SYSTEM.

A pair of nervous cords, situated one on each side of the spinal column, three main "plexuses" in the cavity of the thorax and abdomen, and a large number of smaller ganglia widely distributed over the body, especially in connection with the veins and arteries, constitute the *Sympathetic Nervous System.* Each of these nervous cords consists of a number of ganglia united by intermediate nerves. In the other regions of the spinal column the number of these ganglia equals that of the number of vertebræ (see Fig. 8); but in the region of the neck there are only three ganglia. The three main plexuses are collections of nerve-cells and a dense plexiform arrangement of nerve-fibres. One is situated at the base of the heart; another in the upper part of the abdominal cavity; and the third in front of the last lumbar vertebra.

From the gangliated cord, just described, a communicating and a distributing series of nerve-branches are derived. By the former the sympathetic system is brought into close anatomical and physiological connection with the cerebro-spinal nervous system. The distributory branches of nerves connect the gangliated cord with the viscera and blood-vessels of the body. A recent view (Gaskell, in a paper read May 24, 1888) considers the so-called "sympathetic ganglia," not as representatives of an independent nervous system, but as belonging to the spinal system as truly as do the ganglia of the posterior roots (see Fig. 10). But the former differ from the latter in being efferent rather than afferent; and in that the fibres enter them as medullated but emerge as non-medullated.

The interest which the sympathetic nervous system has for the study of physiological psychology is largely indirect. This fact is partly due to our comparative lack of knowledge respecting its more specific functions. It seems to form a bond between the sensations, emotions, and ideas, which have their physical basis in the cerebro-spinal system, and those organs in the chest and abdomen whose condition is so closely related to such psychical states. The causes of many vague sensations and feelings, and of the coloring of the "background," as it were, of our life in the body, undoubtedly lie, partly, in the stimulation of the nerves of this system by the thoracic and visceral organs. The effect of certain emotions upon digestion, circulation, and other functions of these organs, is too well known to require detailed statement.

THE CEREBRO-SPINAL NERVOUS SYSTEM.

The spinal cord and brain are the great centres of the Cerebro-spinal System. These masses of nervous matter are situated in the bony cavity of the spinal column and the skull.

Membranes of the Spinal Cord and Brain. — The cerebro-spinal nervous substance has three coverings or membranes. These are the *dura mater*, the *arachnoid*, and the *pia mater.*

(1) The membrane lying next to the wall of the bony cavity of the cerebro-spinal axis is called "dura mater." It is white, tough, fibrous. In the skull it becomes identical with the inner lining of the bones. On passing into the spinal column it somewhat changes its character. It puts forth three processes which divide — although only incompletely — the cavity of the skull into two symmetrical halves, and into an upper and a lower space. These processes are (*a*) the *falx cerebri*, sickle-shaped, and extending between the two halves of the large brain; (*b*) the *falx cerebelli*, a similar process between the two lateral lobes of the cerebellum; and (*c*) the *tentorium cerebelli*, an arch over the cerebellum.

(2) The "arachnoid" membrane is transparent, composed of delicate connective tissue. Toward the dura mater it presents a smooth, firm surface. It is reflected on to the roots of the spinal and cranial nerves. The space below this surface is called "subarachnoid"; it is divided into smaller spaces by bundles of delicate tissue, and its inter-communicating areas are filled by an alkaline fluid.

(3) The "pia mater" is a vascular membrane, — a network of fine branches of arteries and veins, held together by delicate connective tissue. It closely invests the nervous substance of both spinal cord and brain; it sends

prolongations into the fissures and columns of the cord, and dips into the fissures between the convolutions of the brain. In this way the minute blood-vessels are brought into the interior of the nervous substance.

These three membranes are not themselves possessed of nervous functions; but by them the nervous masses of the cerebro-spinal axis are protected, held together, "cushioned," and nourished with blood.

Cranial and Spinal Nerves. — The cerebro-spinal axis, or great central nervous mechanism, is connected with the end-organs of motion and of sense by forty-three pairs of nerves. Of these, thirty-one pairs are "spinal nerves," and twelve pairs are "cranial" or "encephalic."

The thirty-one pairs of *spinal nerves* originate in the substance of the spinal cord and pass out of the spinal canal through openings called "intervertebral foramina." Of these, counting from above, the first eight pairs are "cervical," the next twelve "thoracic" or "dorsal"; then five "lumbar," five "sacral," one "coccygeal." Each nerve arises from the side of the cord by two roots, an anterior and a posterior. The former is composed of motor nerve-fibres. The latter is composed of sensory nerve-fibres, and has a swelling or ganglion upon it (see Fig. 10). Immediately beyond the ganglion the two roots unite. The united nerve soon after separates into two divisions, each of which contains both sensory and motor fibres, that are distributed, one upon the back and the other upon the front and sides, to all parts of the trunk and limbs.

The *cranial nerves* are divided by Continental authorities into twelve pairs, and by British authorities into nine. These may be arranged in three groups: (1) the exclusively sensory nerves; (2) the exclusively motor nerves; and (3) the mixed nerves. To the first group belong the olfactory, the optic, and the auditory. To the second

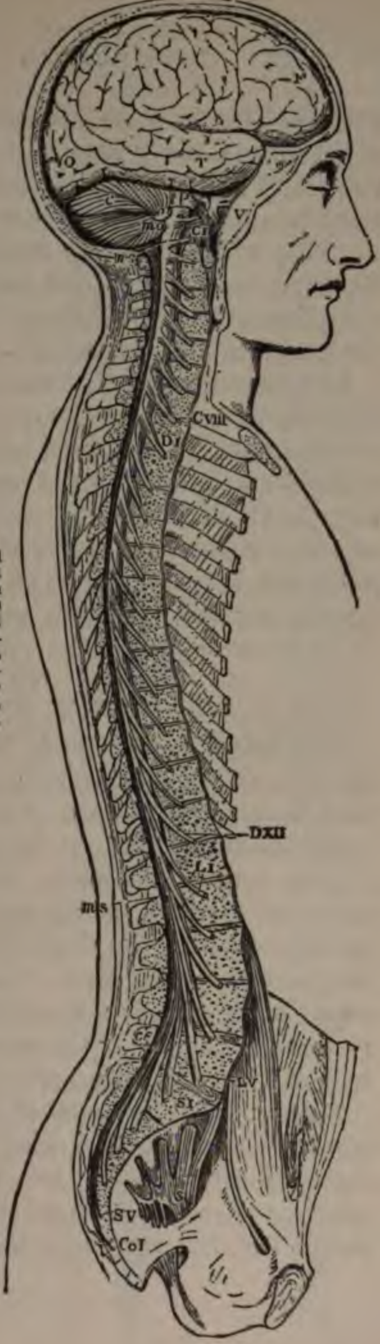

FIG. 8. — View of the Cerebro-spinal Axis. (After Bourgery.) $^{1}/_{5}$. The right half of the cranium and trunk has been removed, and the roots of the spinal nerves dissected out and laid on their several vertebræ. F, T, O, cerebrum; C, cerebellum; P, pons Varolii; *m o*, medulla oblongata; *m s*, *m s*, upper and lower extremities of the spinal marrow. CI. to CVIII. are cervical nerves; DI. to DXII., dorsal; LI. to LV., lumbar; SI. to SV., sacral; CoI., coccygeal.

group belong the nerves that supply the principal muscles of the eyeball, the muscles of facial expression and of the tongue, and the so-called spinal accessory nerve. To the third group belong the three nerves which are distributed so widely over the mucous membranes and muscles of the face, tongue, pharynx, and internal organs, namely, the trigeminus, the glossopharyngeal, and the pneumogastric or vagus (see Figs. 15 and 18).

By these pairs of peripheral nerves the sensory areas of the body have the impulses originating in them conducted to the central nervous mass, while the motor areas are controlled from the same central mass. Thus sensation and perception, which are dependent upon the excited condition of the end-organs of sense, are made possible. And by reflex and automatic action of the cerebro-spinal axis both involuntary and voluntary movements of the trunk and limbs are accomplished through the conducting nerves.

STRUCTURE OF THE SPINAL CORD.

The *Spinal Cord* extends in the spinal canal from the aperture (*foramen magnum*), through which it connects with the brain, downward to opposite the body of the first lumbar vertebra. Here it tapers off into a slender thread of gray nervous substance (*filum terminale*). Its length is, in the adult, from fifteen to eighteen inches. It is nearly cylindrical in shape, its front and back surfaces being somewhat flattened. It has two considerable enlargements of its girth, an upper (*cervical*), from which arise the nerves that supply the upper limbs, and a lower (*lumbar*) which supplies the lower limbs with nerves.

Fissures and Commissures of the Cord. — The spinal cord is almost completely divided for its entire length into right and left halves by two "median" *Fissures;* a somewhat broader one in front (*anterior*), and a somewhat deeper but narrower one behind (*posterior*). Two bands

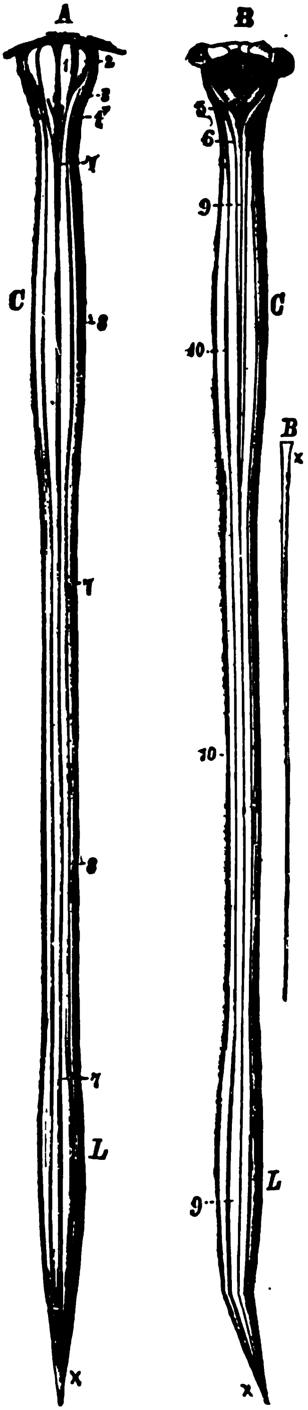

Fig. 9. — A, Anterior, and B, Posterior, View of the Spinal Cord and Medulla Oblongata. B', the Filum terminale, which has been cut off from A and B. 1, Pyramids of the medulla, and 1', their decussation. 2, olives; 3, lateral strands of the medulla; 4', calamus scriptorius; 5, the funiculus gracilis; and 6, the funiculus cuneatus; 7, the anterior, and 9, the posterior, fissures; 8, the antero-lateral depression; 10, postero-lateral groove. C, the cervical, and L, the lumbar, enlargements of the cord.

of nervous matter, called *Commissures*, unite its halves and prevent the fissures from dividing it completely. The front one, at the bottom of the anterior fissure, is the *white commissure;* the one behind, at the bottom of the posterior fissure, is the *gray commissure.* The latter is larger than the former, except at the cervical and lumbar enlargements of the cord. Along its entire length the gray commissure encloses a minute canal (*central canal*).

Columns and Horns of the Cord.—Each half of the cord is subdivided by the entrance of the nerve-roots into three *Columns*. These are (*a*) the *anterior*, which lies between the anterior median fissure and the anterior roots; (*b*) the *posterior*, which lies between the posterior median fissure and the posterior roots; and (*c*) the *lateral*, which lies at the side of the cord between the other two columns.

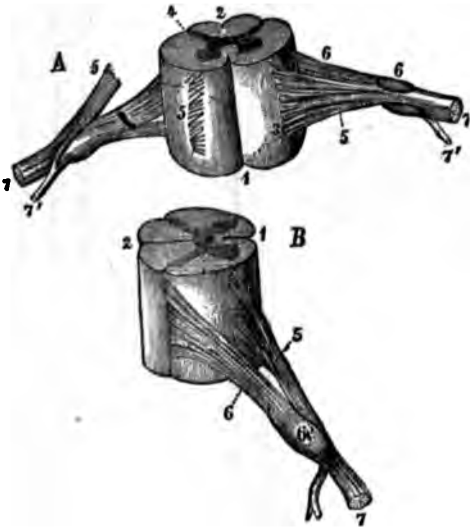

Fig. 10.—A, Anterior, and B, Lateral, View of a Portion of the Cord from the Cervical Region. ²/₁. (Schwalbe.) 1, Anterior median, and 2, posterior median, fissures. At 3, is the antero-lateral depression, over which spread the anterior roots (5). The posterior roots (6), with their ganglion (6'), arise from the postero-lateral groove, and uniting with the anterior roots form the compound nerve (7).

Transverse sections of the cord show that its substance, like all nervous substance, consists of both white and gray nervous matter. The former is external and composes the columns of the cord; the latter is internal and is surrounded by the white matter. The relative amount of the two varies in different portions of the cord. At the lower end of the cord scarcely any white matter is found; the amount of such matter increases from below upwards, and is largest in the cervical region. The amount of gray matter is greatest in the two enlargements of the cord.

The gray columns and their commissures form a figure somewhat like a Roman **H** or a large **X**, or a pair of butterfly's wings. But the lateral masses of these crescent-shaped bodies are narrower in the thoracic region, and broader at the cervical and lumbar enlargements. The limbs of the figure thus formed are called *Horns;* of these horns each side has therefore two, a rounded *anterior* and a longer and narrower *posterior* horn. The division into columns, fairly well marked on the surface, is lost as we pass into the central gray matter. The anterior horn has here an appearance of "spongy substance"; the posterior, of a kernel of such substance surrounded by "gelatinous substance."

White Substance of the Cord. — The external or white matter of the spinal cord, besides connective tissue and lymph- and blood-vessels, is composed of nerve-fibres. The essential part of these fibres is the axis-cylinder; although, when fully developed, they have also the medullary sheath. They vary in size, the thickest being found in the outer portions of the anterior columns ($\frac{1}{1200}$ to $\frac{1}{2000}$ of an inch). In the lateral columns the finer ones lie near the gray matter; but in the posterior columns they increase in thickness as they approach the posterior gray commissure.

The direction of the nerve-fibres in the white substance of the cord is either vertical, or horizontal, or oblique. The vertical fibres are most abundant and are united into fascicles which ascend toward the brain. The horizontal fibres are either *commissural* or *fibres of the roots.* The fibres of the white commissure run horizontally along the median border of the gray matter of the horns, and become interwoven with the vertical bundles of the anterior horns. Most of them pass from the substance of the anterior horn of one side across to the anterior column of the other side.

Fibres of the Roots. — Much interest is attached to the determination of the exact course, in the spinal cord, of the fibres from its anterior and posterior roots. Its intimate structure, as fitted for those reflex functions which are its peculiar property as an organ, is thus understood. The details are given differently, however, by different observers with the microscope. Nor is this strange, since the fibres of the posterior root, especially, divide into bundles so minute and so intricately interwoven with the vertical fibres of the posterior column that their course is extremely difficult to trace.

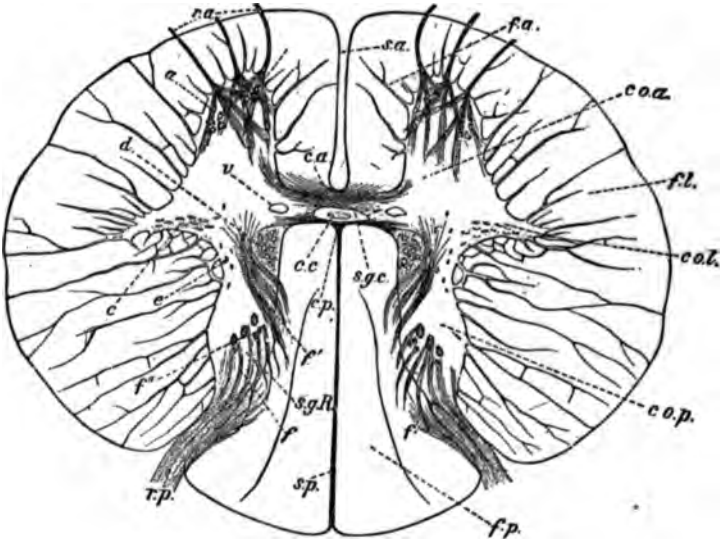

FIG. 11. — Section of the Spinal Cord at the Level of the Eight Pair of Dorsal Nerves. $^8/_1$. (Schematic, from Schwalbe.) *s.a.*, anterior fissure; *s.p.*, posterior septum (or fissure); *c.a.*, anterior, and *c.p.*, posterior, commissures; *c.c.*, central canal; *co.a.*, anterior horn; *co.l.*, lateral horn; *co.p.*, posterior horn; *a*, anterior lateral, and *b*, anterior median, cells; *c*, cells of the lateral horn; *d*, columns of Clarke; *e*, solitary cells of the posterior horn; *r.a.*, the anterior, and *r.p.*, the posterior, roots; *f*, bundle of fibres of the posterior horn; and *f″*, bundle of the posterior column; *f′*, longitudinal fibres of the posterior horn; *s.g.R.*, gelatinous substance of Rolando; *f.a.*, anterior, *f.l.*, lateral, and *f.p.*, posterior, columns.

Most recent authorities recognize two main divisions of the *fibres of the posterior root* on their entrance into the spinal cord. Of these, one, said to be the earliest developed, enters immediately the "gelatinous substance" of the posterior horns and becomes lost in it, or passes through it to form a connection with the cells of the "columns of Clarke" (see Fig. 11). The other portion of the fibres of the posterior roots, said to be developed later, passes for a little way outside of the gray matter along the back part of the lateral column, and then, after running upward a variable distance, buries itself in the gray substance of the posterior horn.

The *fibres of the anterior roots* traverse obliquely the white substance of the cord, and either enter the gray matter of the anterior horns on the same side, or pass by the anterior commissure to the other side of the cord, or pass into the lateral columns and the posterior horns.

Gray Substance of the Cord.—The nerve-fibres which form the principal mass of the gray substance of the spinal cord are generally non-medullated, and frequently divide and subdivide to form extremely minute plexuses. Besides these elements, this substance contains large numbers of ganglion-cells. These cells are described as multipolar and as regularly giving off the two kinds of processes already spoken of (see p. 26). Gerlach thought he could trace the very finest ramifications of the so-called "branching" process of the nerve-cells of the cord until they participated in those plexuses of nerve-fibres which he regards as an essential constituent of its gray substance. Others consider the fate of these processes to be still unknown.

Many of the nerve-cells of the posterior horns are exceedingly small, and are distributed through the above-mentioned plexuses of minute nerve-threads. Indeed, some of the most recent investigations have concluded that the nuclei of the motor nerves in the cord often run into each other, and cannot be distinctly circumscribed. Characteristic groups of ganglion-cells of different sizes also occur at various places in the gray matter of the cord. In the anterior horns of the cervical and lumbar regions there are three such groups of large cells. One other important group is situated at the inner angle of the base of the posterior horn; and, in its extent up and down the cord, it forms the so-called "column of Clarke" (see Fig. 11).

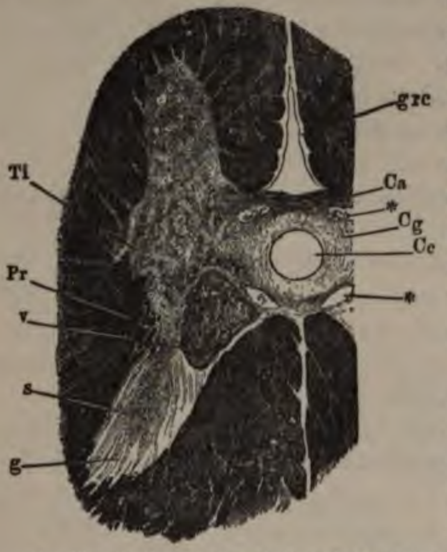

FIG. 12. — Section of Dorsal Part of the Spinal Cord, showing the Gray Matter of the Horns. $^{20}/_{1}$. (Henle.) Ca, anterior white, and Cg., gray commissure; Cc, central canal; v, vesicular column; s, spongy substance of the posterior horn, surrounded by g, gelatinous substance; Pr, reticular process; Ti, intermedian lateral tract.

Tracts in the Spinal Cord. — It is evidently of the greatest importance to trace out those paths of nervous substance along which the nervous impulses may pass in the spinal cord. Neither the microscope nor physiological experiment, however, finds it easy to unravel these paths. Two other methods of their determination are most effective; and when the evidence of both coincides, it may be regarded as fairly conclusive. These methods are the embryological and the pathological. The former makes use of the fact that, in the development of the spinal cord, the medullary substance of the nerve-fibres in different tracts is constituted at different times, so as to render them distinguishable when viewed in cross-section. The pathological method attempts to reach the same result by tracing the lines along which degeneration takes place when the nerve-fibres have been separated from their place of origin and nourishment.

By the methods just described, two principal tracts, which extend along the greater part of the cord, have been made out. From their upper connections they have been named the "pyramidal" and the "lateral cerebellar." The *pyramidal tract* is traceable down from the anterior pyramid of the medulla oblongata. It divides, on entering the upper portion of the spinal cord, into two tracts. Most of its fibres cross over, well up in the cord, and pass down in the back part of the lateral column as a compact bundle. This *crossed* (or lateral) *part* of the pyramidal tract can be traced as far down as the third or fourth pair of sacral nerves. Some of the fibres, however, do not cross in the upper part of the cord. These form the *uncrossed* (or anterior) *part* of the pyramidal tract; on passing downward they gradually diminish, and cease in the dorsal region of the cord.

The *direct lateral cerebellar* tract lies between the lateral pyramidal tract and the outer surface of the cord. It disappears in the lumbar region.

In the posterior white column a tract can be traced as far downward as the middle of the dorsal region of the cord; it is called the "tract (or column) of Goll."

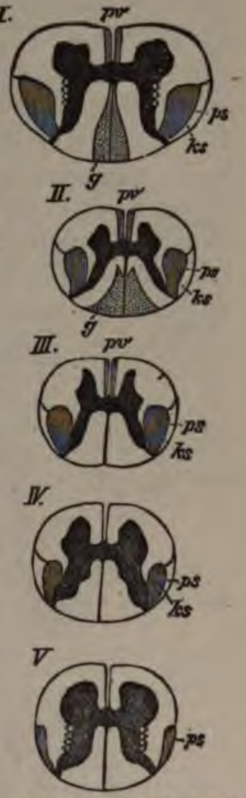

FIG. 13.—Sections through the Spinal Cord at different elevations, to show the tracts of White Substance. *I.*, elevation of the sixth cervical nerves. *II.*, of the third; *III.*, of the sixth; and *IV.*, of the twelfth, dorsal nerves; and *V.*, of the fourth lumbar nerves; *pv*, uncrossed (or anterior) pyramidal tract; *ps*, crossed (or lateral) pyramidal tract; *ks*, direct lateral cerebellar tract; *g*, tract of Goll.

Mechanism of the Spinal Cord. — This brief description of the structure of that nervous mass which lies within the bony cavity of the spinal column shows plainly its adaptation to the general purpose of conducting nerve-commotions up and down, and of acting as a series of reflex and, possibly, automatic centres. Its substance consists largely of ascending and descending tracts of nervous elements. It is also a pile of nerve-centres, each one of which may have its own peculiar functions, but all of which are bound together — up and down, right and left, and obliquely — so as to act unitedly under control of the central organs lying above. It has special local mechanisms; .yet, as a whole, it is connected with the general mechanism of the cerebro-spinal axis. It is adapted to do a great variety of work, as it were, by itself; and yet it can be made to do service under the command of the brain. It is also at various levels — thirty-one in number — bound by the connecting nerve-cords to the end-organs of sense and motion.

STRUCTURE OF THE ENCEPHALON.

The Encephalon, or Brain in the most extended sense of the word, includes all that mass which is contained within

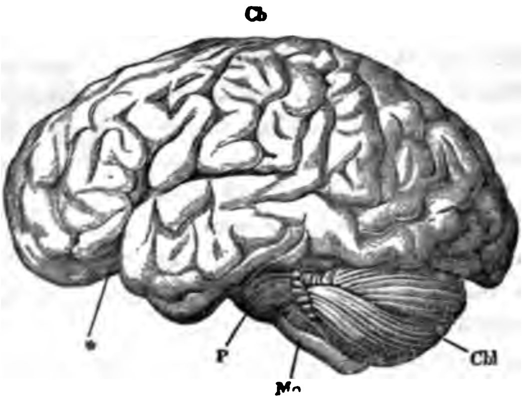

Fig. 14. — View of the Brain in Profile. ⅓. (Henle.) *Cb*, cerebrum; *Cbl*, cerebellum; *Mo*, medulla oblongata; *P*, pons Varolii.

the cavity of the skull. On removing it from this bony cavity four divisions are apparent to any observer. Immediately above the section by which it has been separated from the spinal cord, and appearing as an enlarged prolongation of the cord, is (*I*) the Medulla Oblongata. Covering the upper back part of this organ, and extending beyond it on both sides, is (*II*) the Cerebellum, or Little or Hinder Brain. Swelling out, and in front of the medulla, is (*III*) the Pons Varolii, or so-called "bridge" of the brain. While above both pons and cerebellum, and filling by far the larger part of the cranial cavity, when the entire mass is in its place, is (*IV*) the Cerebrum, or Large Brain, — *the* Brain proper.

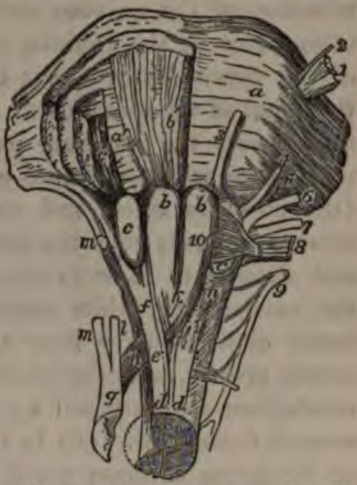

FIG. 15. — Diagrammatic dissection of the medulla oblongata and pons to show the course of the fibres. *a*, superficial, *a'*, deep transverse fibres of the pons; *b*, *b*, anterior pyramids ascending at *b'* through the pons; *c*, *c*, olivary bodies; *c'*, olivary fasciculus in the pons; *d*, *d*, anterior columns of cord; *e*, inner part of the right column joining the anterior pyramid; *f*, the outer part going to the olivary fasciculus; *g*, lateral column of cord; *h*, the part which decussates at *k*, the decussation of the pyramids; *l*, the part which joins the restiform body; *m*, that which forms the fasciculus teres; *n*, arciform fibres. 1 and 2, sensory and motor roots of fifth nerve; 3, sixth nerve; 4, portio dura; 5, portio intermedia; 6, portio mollis of seventh nerve; 7, glosso-pharyngeal; 8, pneumo-gastric; 9, spinal accessory of eighth nerve; 10, hypo-glossal nerve.

External Appearance of the Medulla Oblongata. — This organ is somewhat pyramidal in form, about one and one-fourth inches in length, three-fourths to one inch broad in its widest part, and one-half inch thick. Its *anterior pyramids* appear continuous with the anterior columns of the cord; its *lateral area* shows upon its upper end an elevation called the "olivary body"; its *posterior tracts* appear continuous with the posterior columns of the cord. Just outside the upper part of each posterior tract there ascends to the cerebellum a strong tract named the "restiform body." A part of the posterior tract is marked off from the rest by a septum of the pia mater; this part is called *funiculus gracilis*, which, further upward, broadens out into the *clava*. The back part of the lateral area also broadens out into a wedge-shaped body, known as the *cuneate funiculus*. (For further details, see Fig. 15.)

Internal Structure of the Medulla. — An important re-distribution of the nervous substance, both white and gray, takes place in the medulla oblongata. The arrangement of the nerve-elements thus becomes much more complex than that of the spinal cord. To understand this we must note chiefly the following particulars: (1) The external portions of white substance on the back part of the organ (the posterior tracts and restiform bodies) diverge and become thinner; thus the central gray mass is opened up and allowed to come to the surface between the sides of the surrounding white matter. (2) The great vertical tracts of nerve-fibres from the spinal cord change their course greatly, and other new tracts from the cerebrum and cerebellum are gathered up within this organ, for transmission downward. (3) In this way the central gray mass of the horns becomes much broken, and its distribution changed. A number of large nuclei are also added to the nervous mass in this organ.

The attempt to trace the various tracts of nerve-fibres as they ascend through the medulla from the columns of the cord leads us to notice: —

The Decussation of the Pyramids. — The external white matter of the medulla oblongata is only to a small extent a direct continuation of the columns of the spinal cord. A large bundle of nerve-fibres, which in the cord lies in the back part of the lateral column, pushes its way obliquely through the gray matter of the anterior horn, and passes in front of the central canal to the pyramid of the opposite side. The abrupt passage of so many fibres through it breaks up the anterior horn, separates part of it from the rest, and pushes this separated part over to one side, and close to a part of the posterior horn. The posterior horn also is shifted sidewise by the increased size of the posterior tracts; it comes to lie almost at right angles to the posterior median fissure; its head enlarges and approaches to the surface, which it pushes out into a projection (*funiculus of Rolando*) and higher up, into a distinct swelling (*tubercle of Rolando*).

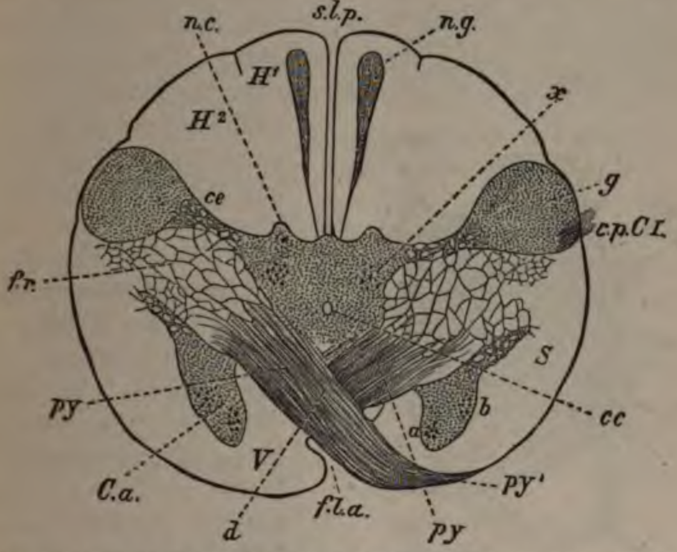

FIG. 16.—Section showing the Decussation of the Pyramids at the point where the Spinal Cord passes into the Medulla Oblongata. $^6/_1$. (Schwalbe.) *f.l.a.*, longitudinal anterior fissure, through which the bundles of pyramidal fibres (*py*, *py'*) are crossing over at *d*; *V*, anterior, and *S*, lateral pyramids; *C.a.*, anterior horn with groups of ganglion-cells, *a* and *b*; *cc*, central canal; *f.r.*, formatio reticularis; *ce*, the neck, and *g*, the head, of the posterior horn; *n.c.*, nucleus of the funiculus cuneatus; and *n.g.*, of the funiculus gracilis; H^1, funiculus gracilis; H^2, funiculus cuneatus; *x*, group of ganglion-cells.

Tracing the principal bundles of fibres from the spinal cord through the medulla gives the following result: The posterior column of the cord forms the substance of the three posterior strands of the medulla; namely, gracilis, cuneatus, and funiculus of Rolando. A great part of the lateral column (the lateral pyramidal tract) passes into the opposite pyramid of the medulla, and ascends toward the cerebrum. Another part (the direct lateral cerebellar tract) passes by the middle of the organ, obliquely backward to the restiform body; but the remainder of it dips under the olives and continues upward. Most of the anterior column of the cord dips under the pyramid of the medulla and passes upward toward the cerebrum; but part of it continues into the pyramid of the same side (see Fig. 15).

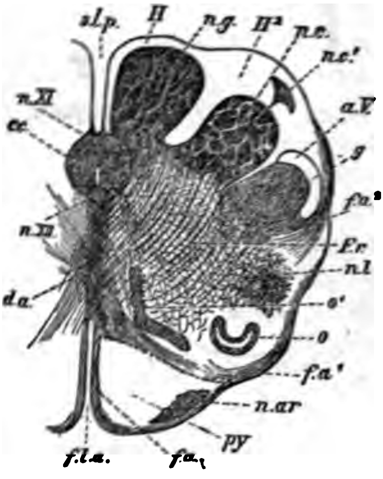

FIG. 17. — Section showing Gray Matter of the Medulla Oblongata, in the region of the upper crossing of the Pyramids. $^4/_1$. (Schwalbe.) *f.l.a.*, anterior, and *s.l.p.*, posterior, fissures; *n.XI.* and *n.XII.*, nuclei of the vagus accessorius and hypoglossal nerves; *d.a.*, so-called upper crossing of the pyramids; *py*, anterior pyramid in which is *n.ar*, the nucleus arciformis; *o*, beginning of the olivary nucleus; o^1, accessory olivary nucleus; *F.r.*, formatio reticularis; *g*, substantia gelatinosa: *f.a.*, *f.a*^{1}, *f.a.*^{2}, arciform fibres.

Formatio Reticularis and Nuclei of the Medulla. — By the "decussation of the pyramids" the substance of the anterior horns of the medulla is broken up into a coarse network (*formatio reticularis*), containing nerve-cells intersected by bundles of fibres. Four special nuclei, of gelatinous appearance, and containing multipolar nerve-cells, are to be noted in each half of the medulla; these are the *nucleus arciformis*, the *nucleus olivaris* or "dentate body," the *nucleus olivaris accessorius*, and the *nucleus pyramidalis*," sometimes called "inner accessory nucleus" (see Fig. 17). Other nuclei consist of those groups of multipolar cells to which the "roots of origin" of certain cranial nerves are traced. These nerve-nuclei receive their names from the nerves whose fibres are supposed to originate in them.

External Appearance of the Cerebellum. — In the Cerebellum the general arrangement of the two kinds of nervous matter is the reverse of that of the spinal cord and the medulla; the gray matter is outside, the white within. This organ may be described as a white or medullary mass, composed of three pairs of large stalks of nerve-fibres, enveloped in a wrinkled covering of gray nervous substance. These three stalks are called the "peduncles" or "crura" of the cerebellum; they serve to connect it with three other organs, with parts of which they are continuous. They are called (1) the *inferior peduncle*, which is identical with the restiform fascicle as it ascends from the medulla to the cerebellum; (2) the *superior peduncle*, which connects the cerebellum forward (with the tegmentum of the crus); and (3) the *middle peduncle*, which passes down on the side into the pons (see Figs. 18 and 19).

The surface of the cerebellum shows two hemispheres

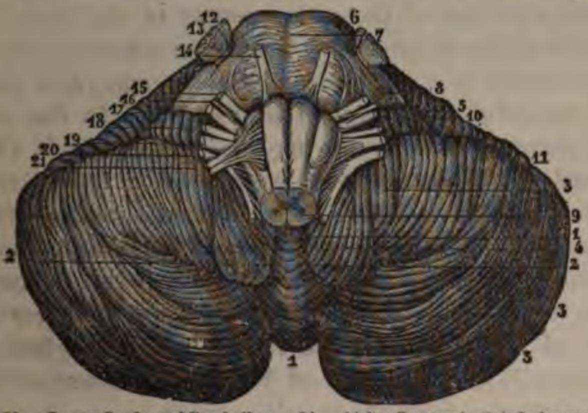

FIG. 18. — Lower Surface of Cerebellum. $^{2}/_{3}$. (After Sappey.) 1, inferior vermiform process; 2, 2, vallecula; 5, flocculus; 6, pons Varolii; 8, middle peduncle of the Cerebellum; 9, medulla oblongata. Various pairs of nerves are seen thus: 12 and 13, roots of fifth pair; 14, sixth pair; 15, facial nerve; 17, auditory; 18, glossopharyngeal; 19, pneumogastric; 20, spinal accessory; 21, hypoglossal.

or *lateral lobes*, united by a central lobe called the ***vermiform process***. The central lobe, on its upper surface, is a mere elevation; but on its lower surface, where it lies at the bottom of a deep depression (*vallecula*), its "vermiform" character is well defined. The surfaces of the cerebellum are divided by fissures into smaller lobes or lobules.

Internal Structure of the Cerebellum. — The interior relations of the nerve-fibres of the peduncles of this organ are extremely intricate, and are not known in much detail. United in a white core, they form a rather uniform mass which is interrupted, however, by certain nuclei of a gelatinous appearance. Several bodies of gray matter are found in this core; of these the more important is disclosed by cutting through a little to the outside of the central lobe. This body (the *corpus dentatum* of the cerebellum) is arranged like the dentate body of the medulla.

The gray matter of the cortex, or rind, of the cerebellum is constructed in a peculiar manner. It consists of thin plates (*lamellæ*) of gray substance, which are penetrated by prolongations of the white matter of the core. The branches of the white matter within the plates of gray substance impart to it an arborescent appearance, and lead to the name of "arbor vitæ" (see Fig. 19). In the cortex itself three distinct layers may be distinguished: (1) an external "molecular layer" having, in a framework of connective tissue, a few roundish cells and minute fibres; (2) an internal layer, which merges gradually into the substance of the core, and contains multitudes of granules whose nature is in doubt; and (3) a middle layer composed of a single irregular row of large ganglion-cells, called "cells or corpuscles of Purkinje." Comparatively large processes from these cells appear to ramify within the outer layer.

Structure of the Pons Varolii. — The Pons, or "Bridge of the Brain," is a thickening of the ventral wall of the fourth ventricle, composed of the middle peduncles of the cerebellum encircling and blending with the continuation upward of the medulla. The general direction of its superficial fibres is transverse, though the lower ones ascend slightly and the superior ones descend somewhat obliquely. On removing these superficial fibres the prolonged fibres of the pyramids are exposed to view; these, as they ascend through the pons, are intersected by transverse fibres.

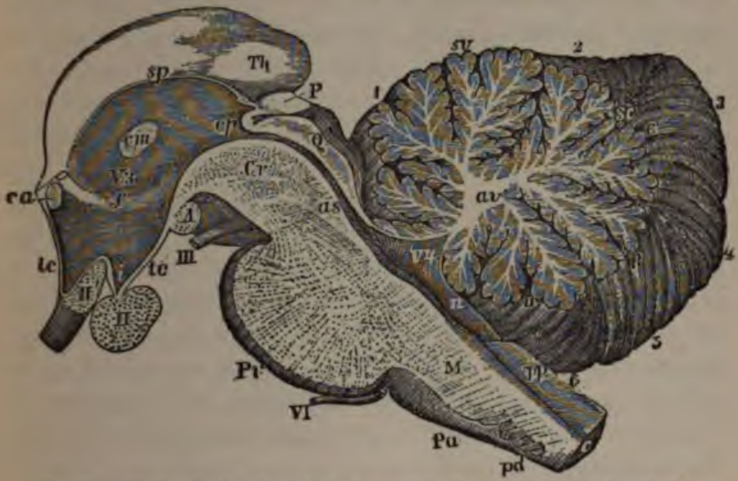

FIG. 19. — Median Section through the Stem of the Brain. (After Reichert.) *M*, medulla oblongata; of which *Pa* are the pyramids, decussating at *pd*; *c*, central canal; *pp*, restiform body; *Pv*, pons Varolii; *V4*, fourth ventricle; *av*, arbor vitæ of the cerebellum; *p*, pyramid; *u*, uvula; *n*, nodule; *as*, aqueduct of Sylvius; *Cr*, crus cerebri; *Q*, corpora quadrigemina; *P*, pineal gland; *Th*, optic thalamus. Commissures: *ca*, the anterior; *cm*, the mollis; and *cp*, the posterior, *V3*, the third ventricle; *A*, corpus albicans; *tc*, tuber cinereum; *i*, infundibulum.

Nuclei of gray matter are found everywhere between the fibres of the ventral part of the pons. The back part of the organ is chiefly constituted by a continuation upward of the *formatio reticularis*, and of the gray matter of the medulla. Several important collections of nerve-cells lie embedded in this reticular formation; the principal of these is the "superior olivary nucleus." Other nuclei in this region give origin to the seventh or facial nerve, and to portions of the fifth nerve.

Structural Significance of the Lower Parts of the Brain. — The very formation of the organs which have just been described is indicative of their service in the mechanism of the cerebro-spinal axis. This service may be said to be of three kinds. They constitute the paths over which the nerve-commotions are to run between the upper brain and the spinal cord. They also serve as organs in which the roots of origin of important pairs of cranial nerves may be planted. And closely connected with these functions is their peculiar adaptability to act as *central* organs. They are arranged more elaborately than the spinal cord, and in more immediate connection with the brain and the higher organs of sense — so as to perform various reflex and automatic functions. But while they share in these general characteristics of structure, they have peculiarities belonging to each.

The medulla oblongata is obviously an organ of conduction between the spinal cord below and the parts of the brain lying above itself. Its peculiarities in discharging this office are twofold. The nerve-tracts from above are greatly compacted, are gathered together — as it were — into shape to be further compressed within the spinal cord. The nerve-tracts from below, on the other hand, are broken up and distributed to the side into the cerebellum and into the principal parts of the crura cerebri. Moreover, a great amount of crossing of the nerve-tracts takes place in this organ. This is significant of the important fact that certain functions belonging to the trunk and limbs of the body are to be connected with the *opposite side* of the higher central organs. It indicates that "right-handed" man is "left-brained." But the enlarged and varied bodies of gray nervous substance which the medulla contains show that it is "packed," as it were, with centres for the discharge of reflex and automatic functions of the lower sort. Some of these would appear to be under the immediate control of the brain above, and others not.

The cerebellum is certainly an organ of very striking structure. It has, in its white core and three pairs of peduncles, the mechanism of a conducting organ. But its many masses of internal gray substance and its gray cortical matter plainly show that it is a great central organ as well. In the aspect of an organ for conduction, its peculiarity is that it is so much to one side of the cerebro-spinal axis. It lies — like an immense system of Y-tracks — out of the course of the direct lines, and yet bound by nervous connections with all the other organs of the encephalon. As a central organ it resembles, far more closely than any of its neighbors, that crowning nervous mechanism, which is called pre-eminently *the Brain.*

The *pons Varolii* appears to be chiefly an organ for condensing and re-distributing the nerve-tracts which it conducts. But its structure is that of a central mechanism as well.

MORE DETAILED DESCRIPTION OF THE CEREBRAL ORGANS.

That portion of the encephalic contents which is called the Cerebrum or Large Brain much exceeds in size all of the rest. Besides the convoluted surface, it contains within its base certain great ganglia; and a number of other nervous masses also appear here. It is of general ovoid shape, and is divided — above, in front, and behind — into two halves or "hemispheres," by a deep longitudinal fissure. If these hemispheres are drawn asunder, they are seen to be connected by a broad white band of nervous matter (the *corpus callosum*). The processes of the dura mater which separate the two halves (*falx cerebri*), and which separate them both from the cerebellum (*tentorium*), have already been described (p. 35).

Under Surface of the Cerebrum.—From the front of the pons very large white nerve-cords are seen passing upward and forward to the cerebrum from the organs lying below ("cerebral peduncles" or *crura cerebri*). Around each of these cords winds a flat band, the *optic tract;* these tracts

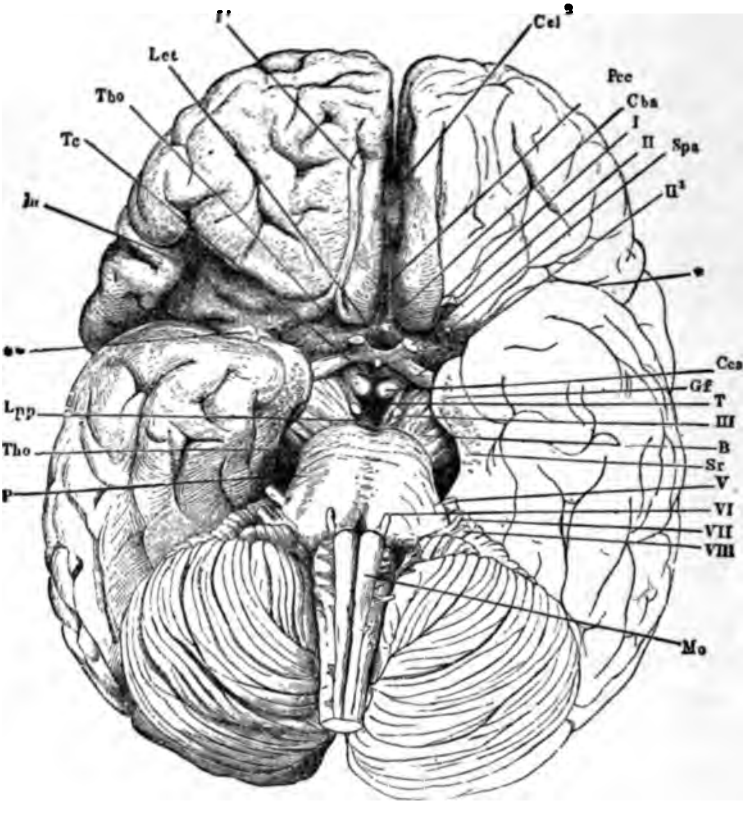

FIG. 20.—Under Aspect of the Brain. (Henle.) B, basis of the crura cerebri; Cca, corpora albicantia; I¹, olfactory bulb; II¹, optic tract; Tc, tuber cinereum; Lpp, posterior perforated space; Ccl, corpus callosum; Lct, lamina cinerea terminalis; Spa, anterior perforated space; T, tegmentum; Tho, thalamus opticus; P, pons; Mo, medulla oblongata; I. to VIII., first to eighth pair of cranial nerves.

come together in front to form the optic commissure, from which the two optic nerves arise. On each side of the deep longitudinal fissure stretches the *olfactory tract*, ending in its bulb. The intercranial part of this nerve is really a projecting portion of the brain. (For the other bodies on this surface, see Fig. 20.)

Upper Surface of the Cerebrum. — On top, the cerebral hemispheres present the appearance of gray nervous matter arranged in folds, called "convolutions" or *gyri*. These are separated by "fissures" or *sulci*, of varying depth. A considerable difference exists in the development of the different convolutions, and in the strength with which the different fissures are marked. The details of this aspect of the brain vary in each individual, and even in the two hemispheres of the same brain. Some sulci and their corresponding gyri appear with a marked regularity in the more fundamental stages of the fœtal brain. They have been divided therefore into primary, secondary, and even tertiary, classes.

Lobes of the Cerebrum. — By means of the primary sulci the hemispheres of the brain have been "mapped out" into five territories, called Lobes. These are the (1) Frontal, (2) Parietal, (3) Temporal or Sphenoidal, or Tempero-sphenoidal, (4) Occipital, and (5) Central or Insula, or Island of Reil. The *frontal* lobe is divided from the parietal, on its upper and lateral surface, by the Fissure of Rolando (*sulcus centralis*); and on its lower surface from the temporal lobe by the horizontal branch of the Fissure of Sylvius. The *parietal* lobe is divided from the temporal, for the greater part, by the Fissure of Sylvius, and from the occipital lobe, on its median surface completely, and on its upper surface only very incompletely, by the parieto-occipital fissure. The *temporal* lobe is separated from the frontal and parietal as already described; but the boundary between it and the occipital lobe is very ill-defined.

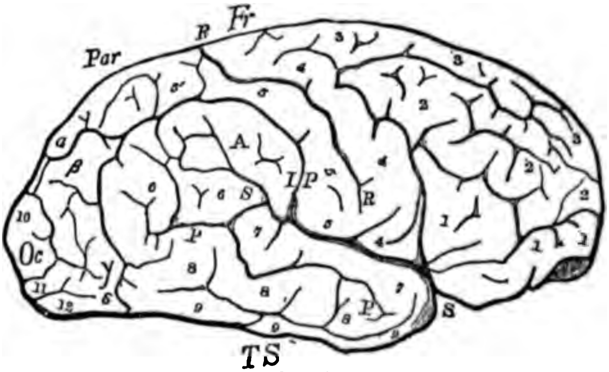

FIG. 21.

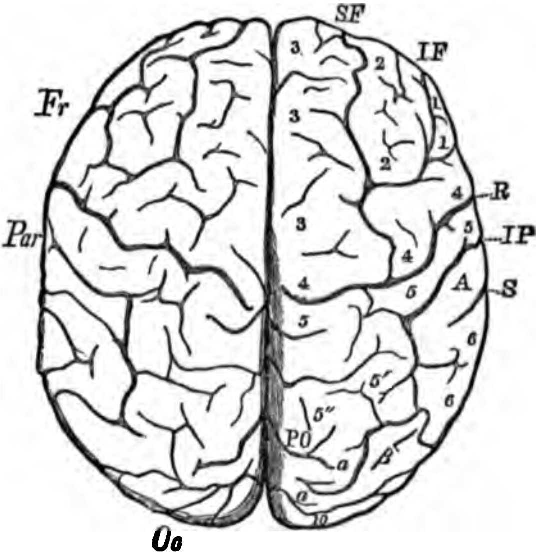

FIG. 22.

FIGS. 21 and 22.—Profile and Vertex Views of Cerebrum. *Fr*, the frontal lobe; *Par*, parietal; *Oc*, occipital; *Ts*, temporo-sphenoidal lobe; *S*, *S*, Sylvian fissure; *R*, *R*, fissure of Rolando; *PO*, parieto-occipital fissure; *IP*, intra-parietal fissure; *P*, *P*, Parallel fissure; *SF* and *IF*, supero and infero-frontal fissures; 1, 1, 1, inferior, 2, 2, 2, middle, and 3, 3, 3, superior frontal convolutions; 4, 4, ascending frontal convolution; 5, 5, 5, ascending parietal, 5′, postero-parietal, and 6, 6, angular convolutions; *A*, supra-marginal, or convolution of the parietal eminence; 7, 7, superior, 8, 8, 8, middle, and 9, 9, 9, inferior temporo-sphenoidal convolutions; 10, superior, 11, middle, and 12, inferior occipital convolutions; α, β, γ, δ, four annectent convolutions.

The *Island of Reil* lies concealed beneath the frontal, parietal and temporal lobes; it consists of a few short convolutions which may be disclosed by drawing aside the margin of the Fissure of Sylvius. In describing the other lobes the boundaries of the *occipital* lobe have been sufficiently defined.

Sulci and Gyri of the Upper Surface.—The frontal, temporal, and occipital lobes all have three principal convolutions arranged in nearly parallel tiers (superior, middle, and inferior). On each side of the Fissure of Rolando are the two central convolutions, sometimes called "ascending frontal" and "ascending parietal." Among the sulci, the Fissure of Sylvius is much the most important. It exists in the fœtal brain at the third month, and is made by folding the entire hemisphere into an arch. The Fissure of Rolando is also always present in the human brain, and is rarely or never bridged over by a secondary gyrus. It appears in the fœtus as early as the end of the fifth month. (For further details, see Fig. 22.)

Median Aspect of the Cerebrum.—On this aspect of each hemisphere appears an important convolution which arches around the corpus callosum, and is separated from the first

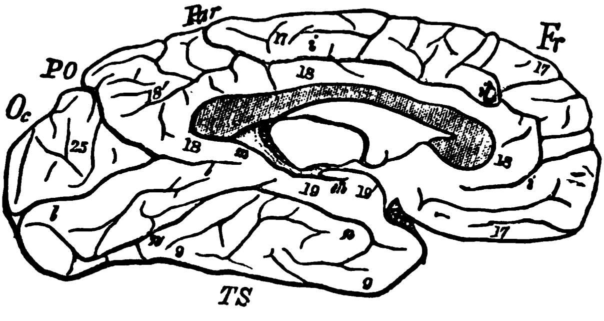

Fig. 23.—Convolutions of the Inner and Tentorial Surfaces of the Left Hemisphere. *i*, *i*, *i*, calloso-marginal fissure; *l*, *l*, calcarine fissure; *m*, *m*, hippocampal fissure; *n*, *n*, collateral fissure; *PO*, parieto-occipital fissure; 17, 17, marginal convolution; 18, 18, gyrus fornicatus; 18′, quadrilateral lobule; 19, hippocampal gyrus; 19′, its recurved end; 25, occipital lobule; 9, 9, inferior temporo-sphenoidal convolution.

frontal convolution by a deep and constant fissure (the *sulcus calloso-marginalis*); it is called from its shape, *gyrus fornicatus*. Its back end curves downward and forward under the name of *gyrus hippocampi*, to the inner tip of the temporal lobe. The passage without break of one of these convolutions into the other is considered by Ecker to be a most important difference between the hemispheres of the brain of man and those of the ape. (For further details, see Fig. 23.)

Spaces and Bodies within the Cerebral Mass. — By cutting off successive slices of the cerebral hemispheres their general internal structure may be exposed. Beneath the corpus callosum, and roofed over by it, is a space in the interior of each hemisphere. These cavities are called *lateral ventricles*. They are separated by a thin transparent wall (the *septum lucidum*), and are moistened by a serous fluid. The roof of another cavity, the *third ventricle*, is formed by an expanded fold of the pia mater (*velum interpositum*). Each lateral ventricle has a central space and three curved prolongations, or *cornua*, (the anterior, the posterior, and the descending,) which extend into the cerebral mass.

On the floor of each lateral ventricle the exposed portions of the great "basal ganglia" of the cerebrum are visible. Two large pear-shaped bodies of gray color are here seen, with their broad extremities directed forward into the anterior cornua of the ventricle, and their narrow ends outward and backward. They are called, from their striped appearance when cut open, "striate bodies" or *corpora striata*. Between the diverging portions of these bodies are certain ovoid masses called "optic thalami." Each thalamus rests upon one of the crura cerebri; on its outer and back part are two small elevations (*corpora geniculata*, *internum* and *externum*). Along the floor of the descending cornu of the ventricle, the inner surface of the gyrus fornicatus, doubled upon itself like a horn, appears as a white eminence (*hippocampus major* or "horn of Ammon"). An arch-shaped band of nerve-fibres, called the "fornix," is situated beneath the corpus callosum. It consists of two lateral halves which, in front, form two pil-

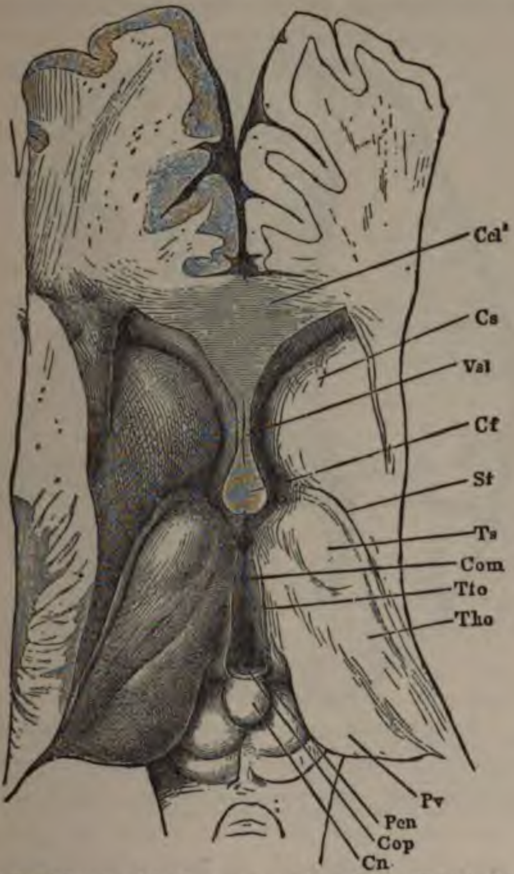

FIG. 24.—Basal Ganglia of the Cerebrum seen from above. (Henle.) Ccl, genu of the corpus callosum; Cs, corpus striatum; Vsl, ventricle of the septum lucidum; Cf, column of the fornix; St, stria terminalis; Tho, optic thalamus; and Ts, its anterior tubercle; Com, middle commissure between the thalami and over the third ventricle; Pv, pulvinar; Cn, conarium or pineal gland; Cop, corpus quadrigeminum.

lars that descend to the base of the cerebrum and become the *corpora albicantia.* Behind and between the optic thalami, and resting on the back surface of the crura cerebri, are four eminences in two pairs, called *corpora quadrigemina;* the front pair are the *nates;* the back pair, *testes.*

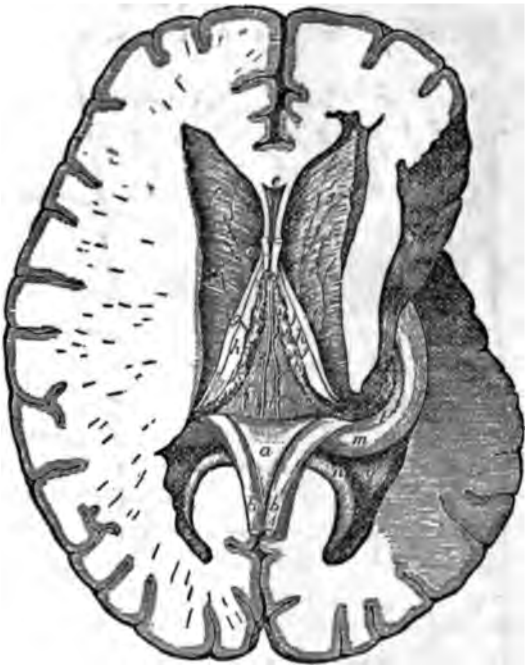

FIG. 25. — A Deeper Dissection of the Lateral Ventricle, and of the Velum Interpositum. *a*, under surface of corpus callosum, turned back; *b, b*, posterior pillars of the fornix, turned back; *c, c*, anterior pillars of the fornix; *d*, velum interpositum and veins of Galen; *e*, fifth ventricle; *f, f*, corpus striatum; *g, g*, tænia semicircularis; *h, h*, optic thalamus; *k*, choroid plexus; *l*, tænia hippocampi; *m*, hippocampus major in descending cornu; *n*, hippocampus minor; *o*, eminentia collateralis.

The structure of some of the bodies already referred to requires a yet more detailed description, in order to even an elementary knowledge of the superior cerebro-spinal mechanism.

The Crura Cerebri. — These strong peduncles of the brain ascend from the pons to the optic thalami and the striate bodies. The fibres which constitute them are arranged in two groups, separated by the gray matter of the *substantia nigra*. The front portion is called *crusta*. Of its fibres an important part is continuous with the longitudinal fibres from the pyramids of the medulla; it receives other fibres from the substantia nigra. Many of the fibres of the crusta run to the nuclei of the striate bodies and terminate there; but some radiate upward through the internal capsule directly to the cerebral cortex.

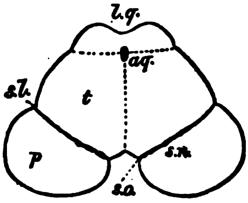

FIG. 26. — Section through the Mid-brain. (Schwalbe.) *aq.*, aqueduct of Sylvius; *s.n.*, substantia nigra; *p*, crusta of the crus cerebri; *t*, tegmentum of the crus cerebri.

The back portion of the crus is called *tegmentum*. Some of its fibres come from the anterior column of the cord and radiate upward to the optic thalami. These fibres are diffused. Others are collected into more well-defined tracts, — especially a tract coming from the superior peduncle of the cerebellum, and passing forward over the anterior end of the fourth ventricle (see Fig. 19).

The formatio reticularis is continued into the tegmentum, and some fibres appear to arise in its cells.

The Striate Bodies. — Each *corpus striatum* consists of two masses, the upper one of which (*nucleus caudatus*) projects into the lateral ventricle; the lower one (*nucleus lenticularis*) is embedded in the white substance of the hemisphere, and constitutes the principal part of the body. These two are separated by an important layer of white matter called the "internal capsule."

The details of the structure of the striate bodies are insufficiently made out. The nucleus caudatus receives from the capsule, on the side turned toward it, several bundles of fibres. All parts of the nucleus lenticularis are pervaded with bundles of white fibres. Some bundles pass into it from the adjacent parts of the capsule; some connect it with the caudate nucleus; some radiate from it toward the cerebral cortex. The gray matter of this organ has free nerve-nuclei distributed through it.

The striate bodies have apparently a special connection with the frontal and parietal lobes, but also with some convolutions of the temporal lobe and the Island of Reil.

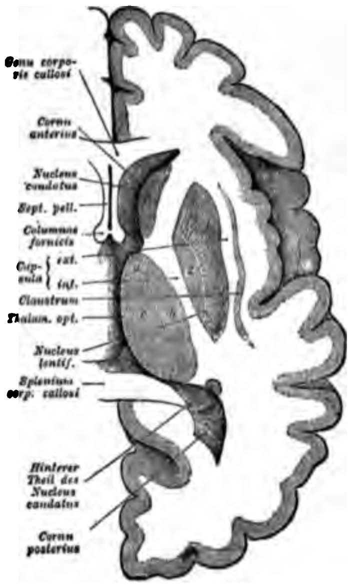

FIG. 27.

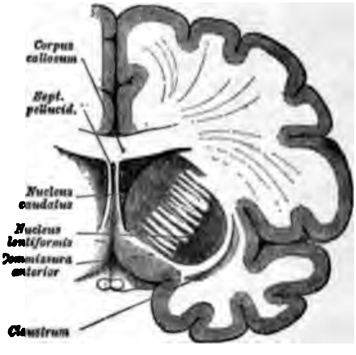

FIG. 28.

These and the following two Figures show the arrangement of the white and gray substance in the interior of the cerebrum. (All four are from Gegenbaur.)

FIG. 27. — Horizontal Section through the Right Hemisphere.
FIG. 28. — Frontal Section through the Cerebrum in front of the Fornix. Posterior surface of the section displayed.

The Optic Thalami. — The gray matter of this organ is subdivided into several parts, so that two or more nuclei are distinguished by different authorities. This subdivision is only partial, however; the organ is therefore, perhaps, best described as a mass of gray nervous substance, with multipolar and fusiform cells, and everywhere traversed by nerve-fibres. Its external and under surfaces are not free, but are united with other parts of the brain.

On the outer surface of the optic thalami is the white matter of the internal capsule, composed of fibres diverging from the crusta into the hemispheres. With these fibres mingle those which radiate from the interior of the organ itself. According to a recent authority, the thalamus is the primary centre of the optic nerve.

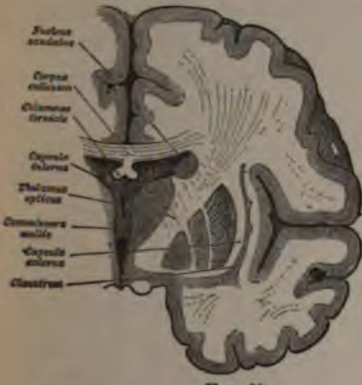

FIG. 29.

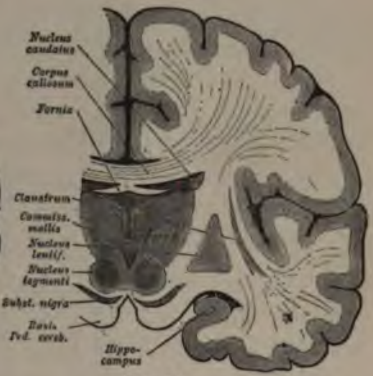

FIG. 30.

FIG. 29. — Frontal Section through the Right Hemisphere of the Cerebrum in front of the Commissura Mollis. Posterior surface of section displayed.

FIG. 30. — Frontal Section through the Cerebrum back of the Commissura Mollis. Front surface of section displayed.

The Corpora Quadrigemina. — In the interior of the front pair the most characteristic portion of this organ is found; it is a layer of fine nerve-fibres running longitudinally, between which are small, scattered nerve-cells. In the external strata of these bodies multipolar cells are abundant; in the interior, at the sides of the Sylvian aqueduct, is a collection of gray matter which is continuous with the lining of the third ventricle. The third and fourth nerves originate in the nervous substance which lies along this "Aqueduct" (see Fig. 20).

Layers of the Cerebral Cortex. — The general arrangement of gray nervous substance upon the surface, and of white matter within, is adhered to in all parts of the cerebral cortex. But the form and distribution of the nerve-cells are different in different regions and in different layers of the same region. As a rule the cortex has five layers or *laminæ.* The entire thickness is, in the adult, from $\frac{1}{12}$ to $\frac{1}{8}$ inch. The first layer shows delicate nerve-fibrils run-

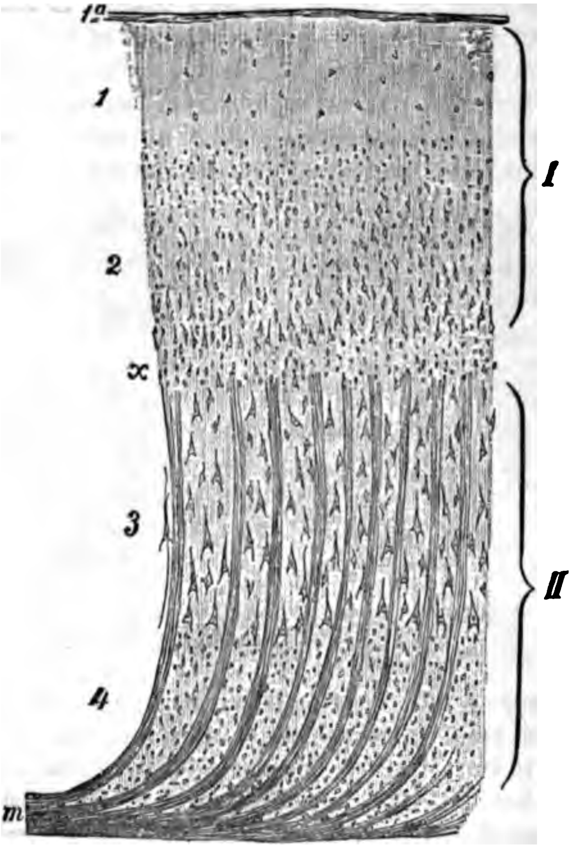

FIG. 31. — Section through the Cerebral Cortex of Man, prepared with Osmic Acid. $^{45}/_{1}$. (Schwalbe). *I*, principal external, and *II*, internal, layer; *x*, layer lying as a limit between the two; *m*, medullary substance sending out bundles of nerve-fibres into *II*; *1*, layer poor in cells, but with an external plexus of nerve-fibres (*1a*); *2*, layer of small, and *3*, of large, pyramidal cells; *4*, inner layer of small nerve-cells.

ning parallel to the surface and interlacing with a few small branching nerve-cells. The second and third layers contain a large number of pyramidal or spindle-shaped cells. In the second layer the cells are about $\frac{1}{2500}$ inch in diameter, and are closely pressed together. In the third are fewer cells, but they increase in size to perhaps $\frac{1}{1000}$ or $\frac{1}{800}$ inch, and have their long axes perpendicular to the surface. The fourth layer contains large numbers of small, globular, and branching cells; the fifth, spindle-shaped bodies with long tapering processes, and smaller irregular cells, very compactly accumulated.

The number of nerve-cells in the cortex is enormous. In a bit of its substance, 1 millimeter square and $\frac{1}{10}$ millimeter thick, 100 to 120 have, on an average, been counted.

Modifications of the arrangement just described are found in certain regions of the cerebral cortex. In the occipital lobe, for example, the number of layers is increased, by intercalating granule layers, to seven or eight. In certain layers, called "motor," large cells (named by Betz "giant-cells") resembling those in the anterior horns of the spinal cord, are found. Conjecture and research are at work with the question, whether certain of these layers, and the cells they contain, are not more distinctively sensory, and certain others more distinctively motor. This subject is very important in its relations to our entire conception of the nature and functions of the cerebral mechanism. But as yet histology, even when aided by physiological experiment, has determined nothing definite.

Systems of Cerebral Nerve-fibres. — The nerve-fibres of the white substance of the brain are of three classes, according to the destination of the fascicles into which the fibres are gathered. There are the (1) downgoing or peduncular, (2) the commissural, and (3) the arcuate (*fibrae propriae*). The *peduncular* system of nerve-fibres connects the cerebrum with the lower parts of the encephalon. This system is called the *corona radiata*; it is the "blossoming out" of the nerve-fibres on their way between the hemispheres and the lower ganglia. Looked at from above, this system represents the contracting of the downgoing nerve-tracts as they are narrowed into the internal capsule and then taken on to the crura cerebri. (See Fig. 27.) A considerable portion of this system, however, terminates in the optic thalami and the striate bodies.

The principal tract of the *commissural* system of cerebral fibres is formed in the corpus callosum. This system connects the two hemispheres of the brain. That the fibres of the corpus callosum are not wholly commissural, follows from the fact that, since this commissure lies above the plane of the corona radiata, the peduncular system, on its way to the hemispheres, here intersects with the commissural. A smaller commissure (the *anterior*) passes below the lenticular nuclei of the striate bodies and connects the convolutions around the Sylvian fissure.

The system of *arcuate* fibres of the cerebrum connects the gray matter of more or less distant convolutions of the same hemisphere. These fibres may often be described as a "garland-like interweaving" of two convolutions around the sulcus between them. In certain localities, where the fascicles into which the fibres are gathered are strongly marked, they have received special names; such are the *fasciculus uncinatus*, which crosses the bottom of the Sylvian fissure, the *fillet of the gyrus fornicatus*, extending longitudinally in that convolution, etc. The function of the arcuate fibres is plainly that of joining into a diversified unity the different portions of each cerebral hemisphere.

PATHS OF NERVOUS IMPULSES IN THE SPINAL CORD AND BRAIN.

The foregoing brief description of the cerebro-spinal nervous system shows that it is a mechanism constructed so as to afford "Tracts" or "Paths," to a greater or less degree distinct, for the transmission of nervous impulses. It is, however, only to a very limited degree that histology alone, or even when helped by embryology and pathology, can make out precisely where these paths lie. (Several of those belonging to the spinal cord, that are more distinctly traceable by the histological method — for example, the pyramidal tract, both crossed and uncrossed, the direct lateral cerebellar tract, the paths of the anterior and of the posterior nerve-roots, etc. — have already been described.) In the brain also it is thought by eminent authorities that certain chains of nervous organs, in which the gray masses are successively connected by nerve-cords between, can be pointed out. With this in view, three collections of nervous matter (the locus niger, and the two nuclei of the striate bodies), with the bundles of nerve-fibres which bind them together, have been called "ganglia of the crusta" by Meynert. Another chain, consisting of the tegmentum, the red nucleus (a collection of large pigmented cells near the Sylvian Aqueduct), the corpora geniculata, and the optic thalami, has been proposed by the same authority.

It is only, however, when the aid of physiology (pathological and experimental) is summoned, that much progress toward certainty can be made in determining paths of nervous impulse within the cerebro-spinal axis. Even with this aid, there is still room for conjecture and uncertainty. Anticipating additional evidence which will subsequently be more fully described, we now indicate the probabilities concerning certain of these paths.

Paths in the Roots of the Spinal Cord. — The honor of the truly "epoch-making" discovery, that the anterior roots of the spinal cord are motor and the posterior, sensory, must be divided between Sir Charles Bell and Magendie. This discovery may be said to have opened the door to modern experimental physiology. The demonstration of the fact is performed by dividing these roots, respectively, and then observing the physiological results. When a posterior root is divided, all the structures supplied by the divided nerve lose their sensibility; while the muscles supplied by the corresponding anterior root continue to be thrown into action by the will and by reflex stimulation. In this case also, stimulation of the central end of the divided root produces sensory effects; but stimulation of the peripheral end produces no motion. When an anterior root is divided, on the contrary, the muscles supplied by the nerves of this root cannot be made to act by will; but no sensory paralysis is produced. Moreover, stimulation of the peripheral end of the nerve will now throw the muscles into contraction; but stimulation of the central end will produce no effects. Thus far, then, the paths in the spinal cord may be said to be distinctly traceable.

Paths in the Anterior Columns of the Cord. — The general arrangement of the motor paths in the anterior part of the spinal cord is maintained throughout. Histology has shown us, however (p. 40), that the two halves of the cord are bound together by the commissures; this fact suggests a crossing, at least partial, from one side to the other, of the nervous impulses. Experiment upon the lower animals seems to show that a partial crossing of the motor paths takes place in the cord. In man's case, most if not all of this crossing from side to side, so far as the paths of voluntary motion are concerned, occurs very high up, if at all, in the spinal cord. But the structure of this organ is such as plainly to provide for an intermingling of the paths of the sensory and the motor roots at about the same level. Thus its character as a pile of centres is maintained.

Paths in the Posterior Columns of the Cord.—In the posterior parts of the spinal cord are the paths by which the sensory impulses chiefly run from the posterior roots up to the brain. These paths also seem to undergo a partial crossing from one side to the other in the cord. In the lower animals, according to the evidence of experiment, the sense of feeling is retained after the cord has been cut entirely through from the front to the posterior columns. Stimulation of these columns produces signs of pain and other sensory effects. Some investigators would confine the paths, by which sensory impulses of *touch* pass along the cord, to the posterior columns; they would assign to the gray matter of the cord, the paths for impulses giving rise to sensations of pain. Others consider that these columns conduct sensory impulses only so far as the nerves from the sensory roots pass through them; it is then the gray substance which carries these impulses upward. The conclusions by which some experimenters locate motor, and even voluntary motor, paths in the posterior columns, are extremely doubtful.

Paths in the Lateral Columns of the Cord.—In these portions of the spinal cord both the paths of motor and those of sensory impulses are found. As to the former there is little or no dispute. As to the existence of sensory paths in the lateral portions of the cord, the evidence of experiment is somewhat conflicting; but, on the whole, it seems to favor an affirmative conclusion. This conclusion accords well with histology.

It must be remembered that, when we speak of "paths in the spinal cord," we are not to think of a perfectly fixed and rigid course like that of the iron rails upon which a locomotive runs. No nerve-commotion, when started in any portion of the cord, is necessarily and under all circumstances compelled to take one, and only one, path to its destination. Secondary paths, besides the primary and more ordinary paths, exist in abundance. A considerable work of substitution, especially as regards the tracts along which the sensory impulses move, may then take place. Even in the case of the voluntary motor tracts in man, although such a work of "substitution" apparently does not take place, a certain latitude of movement from a straightforward course undoubtedly exists.

Paths in the Brain. — The evidence already presented from histology indicates that certain tracts, probably motor, pass from the crusta through the internal capsule, without entering the basal ganglia, into the frontal and parietal convolutions. Other tracts, which are probably sensory, run through the tegmentum, enter the thalamus and subthalamic region; then, after being redistributed, emerge to find their way to the temporal and occipital lobes. How well physiological experiment agrees with this general conclusion, we shall see subsequently.

The paths by which the sensory impulses travel in the brain must be exceedingly intricate; for the phenomena connected with all sensory disturbances are very complicated and often conflicting. For example, if a sensory cranial nerve is severed, the different functions of feeling pain, of pressure, and of temperature, and the power of localization, in the region supplied by that nerve, are all lost. But disease of the cerebro-spinal axis may impair one or more of these functions, and leave the other intact. Again, loss of the sense of temperature and of the muscular sense rarely occur separately; but muscular sense frequently disappears and the sensitiveness of the skin to pressure is retained.

The paths both of motor and of sensory impulses, cross in the region of the pons Varolii and medulla oblongata. All the paths of both kinds lie very close to each other in the white nervous substance surrounding the basal ganglia. There is considerable recent evidence[1] to show that the tracts followed by impulses of muscular sensation pass through the posterior columns or cornua of the spinal cord, and are gathered into more or less distinct bundles, at the back part of the internal capsule, before they diverge to enter the hemispheres.

The confidence with which M. Luys, in his work on the "Brain and its Functions," has localized the paths of motor impulses wholly in the striate bodies, and those of the different sensory impulses, olfactory, visual, tactual, auditory, in those four centres of the optic thalami which he distinguishes, cannot be maintained. The tendency of modern investigation is to place more emphasis upon the fibrous nerve-matter surrounding these organs as furnishing paths for the conduction of both kinds of impulses.

Substantially, in its more obvious outlines, as we have described it, but with an infinite and indescribable complexity of details, is constructed this marvellous mechanism of the nervous system. Some of the more particular functions of its parts will be investigated in other connections. But even this description shows its fitness to serve as a physical basis for the equally indefinite and indescribable complexity of the mental life. How many variations of fundamental types do the organs of the physical mechanism display! And of how many kinds, shades, degrees of intensity, and modes of local coloring, are our sensations and their representative images susceptible! The immense variety and essential unity of this physical basis suggest a corresponding variety in unity of the psychical life.

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[1] Bastian, in Brain, April, 1887, p. 69 f.

CHAPTER III.

STRUCTURE OF THE ORGANS OF SENSE AND MOTION.

In the general division of labor among the organs of the nervous system, certain groups of cells at the surface of the body become especially sensitive to external stimuli. These cells accordingly acquire the special function of receiving and modifying the action of such stimuli, and thus of setting up in the conducting nerves a neural process which is propagated to the central organs. Every "end-organ," therefore, looks both inward and outward.

Significance and Kinds of End-organs. — The end-organs are divided into two classes: first, end-organs of sense, and second, end-organs of motion. The former are in general made up of cells, which, posteriorly, pass into nerve-threads that are gathered into the nerve of special sense; and which, anteriorly, develop conical or fusiform processes. The simplest type is, then, a hair-like process extending outward and connected by a sensitive cell with a nervous filament extending inward. Only a small part, however, of what are called "the organs of the special senses" belongs to the nervous system. The greater part (as, for example, of the ear, the eye, the skin) consists of mechanical contrivances designed to modify the external stimulus, while conducting it to the truly nervous mechanism.

End-organs of Smell. — That portion of the mucous membrane of the nose which clothes the upper region of the nasal cavity, and is called *regio olfactoria*, contains the end-organs of smell. Two different kinds of cells are here discovered. By Max Schultze and most other investigators, one of these is considered non-nervous and *epithelial*, the other nervous and *olfactory*. The epithelial cells are the larger, have an oval nucleus of considerable size, and extend through the whole epithelial layer. The olfactory cells are spindle-shaped, with a round nucleus, and very fine long processes. Other investigators believe that this difference is not a fixed distinction of kinds, but is rather indicative of different stages of development. The exact relation of the fibrils of the olfactory nerve (which is the specific nerve of smell, and really, in part, a lobe of the brain) to the epithelium of this region is not made out. It seems probable, however, that they do not pass directly into the processes of the end-organ cells, but are lost in a network whose interstices are filled up with nerve-granules.

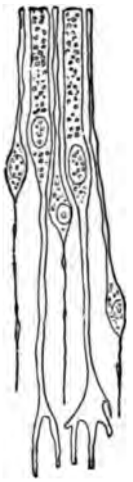

FIG. 32. — Olfactory Cells and Epithelial Cells from the Mucous Membrane of the Nose. $^{500}/_{1}$. (After Schultze.)

The contrivance for bringing the stimulus to the end-organs of smell is comparatively simple. It is necessary only that a current of air, in which the stimulating particles float, should be drawn over the mucous membrane of the region. Since in expiration the current is carried past the sensory parts without striking them, smelling is almost entirely confined to inspiration. When "snuffing," we increase the amount and force of the air drawn into this region, by first creating a partial vacuum in its cavity.

End-organs of Taste. — On the upper surface of the root, and on the borders and apex of the tongue, and in some cases, on the anterior portion of the soft palate, are found certain *papillae*. Of those papillae which contain the end-organs of taste two kinds are distinguished; the *circumval-*

latæ and the *fungiformes*. The circumvallate papillæ are composed of connective tissue invested by epithelium arranged in plates (*laminæ*). At the sides where the epithelial layer is thinner, the end-organs of taste form a zone which extends upward to the level where the papillæ are no longer protected by the lateral wall. In the fungiform papillæ these organs appear in the epithelium which covers their upper surface, and in the surfaces of the sides.

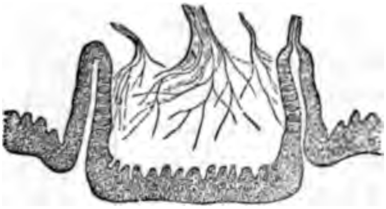

FIG. 33. — Transverse Section through a Papilla Circumvallata of a Calf. Showing the arrangement and distribution of the gustatory bulb. $^{25}/_{1}$. (Engelmann.)

The Gustatory Flasks. — These structures, sometimes called "gustatory knobs" or "bulbs" occupy flask-shaped cavities in the papillæ, which they completely fill. Their lower part rests on connective tissue; their upper part or neck has an opening or *pore*, of from $\frac{1}{4000}$ to $\frac{1}{1250}$ inch in diameter. Each flask consists of from fifteen to thirty long, thin cells, arranged like the leaves of a bud around its axis. The margin of the pore is formed by bringing several cells together.

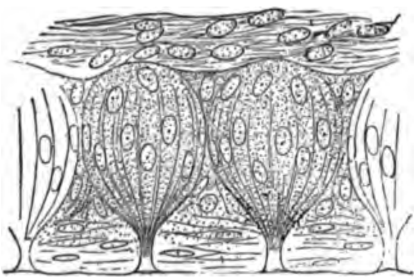

FIG. 34. — Gustatory Bulbs from the Lateral Gustatory Organ of the Rabbit. $^{450}/_{1}$. (Engelmann.)

The gustatory flasks also are composed of two kinds of cells, one *epithelial*, the other *gustatory*. The epithelial or "investing" cells are long, narrow, bent, spindle-shaped, with a nucleus well marked. The outward end is pointed, the central end branching. The gustatory cells are thin, long, and highly refractive of light, with nearly the whole body occupied by an elliptical nucleus. The body of the cell is elongated into two processes; the upper one of which is broad, but bears a short, fine point, like a stiff hair. This point lies in a canal and rarely projects from the pore of the flask.

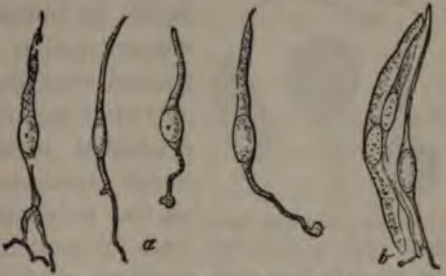

FIG. 35.—*a*, Isolated Gustatory Cells, from the Lateral Organ of the Rabbit; *b*, an Investing and Two Gustatory Cells, isolated but still in connection. $^{600}/_{1}$. (Engelmann.)

The *glosso-pharyngeal* nerve is the principal nerve of taste; but the lingual branch of the trigeminus is thought by some to take part in sensations of this sense. The nerve is distributed to the back of the tongue, then enters the papillæ where it forms a minute plexus interspersed with nerve-granules. Its connection with the nerve-cells of sense is probably indirect, through this plexus and its granules.

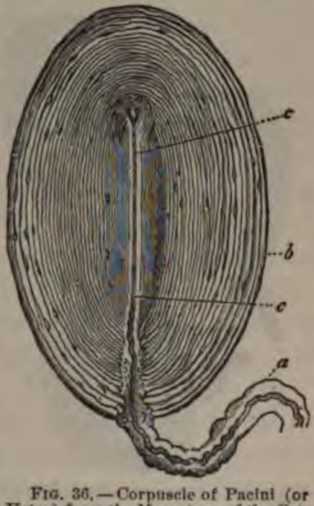

FIG. 36.—Corpuscle of Pacini (or Vater) from the Mesentery of the Cat. (After Frey.) *a*, nerve with its sheaths; *b*, system of tunics constituting the capsule of the corpuscle; *c*, axial canal, in which the nerve-fibre ends.

End-organs of Touch.—The sensory nerves distributed to the skin, the organ of touch in the larger sense of the word, terminate either in free end-fibrils or in special structures called "tactile corpuscles" or "end-bulbs." These special structures have been named after different investigators. The three or four different kinds may, however, be considered as modifications of one type. The first of these structures to be discovered (more than a hundred and fifty years since, by Vater) was the so-called "Corpuscle of Pacini" (or Vater). These bodies consist of layers of connective tissue, arranged concentrically, and most closely packed near the centre. The layers surround a cavity containing a soft, nucleated material into which the nerve penetrates. The axis-cylinder of the nerve-fibre which enters the bulb is finely fibrillated. The bulb consists of granular substance. In man these bodies abound in the palms of the hand and the soles of the feet; but especially in the palmar surfaces of the fingers and toes. In some places they are visible to the naked eye as a minute grain $\frac{1}{10}$ to $\frac{1}{8}$ inch in diameter.

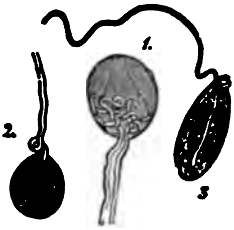

FIG. 37. — End-bulbs from the Conjunctiva of the Human Eye. (After Kölliker.) *1*, has two nerve-fibres which form a coil within the end-bulb; *2*, has a fatty core. The nerve-fibre of *3* ends within in the form of a knot.

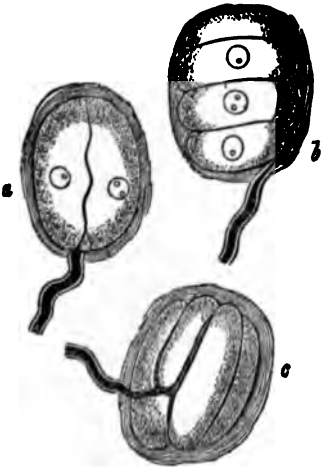

FIG. 38. — Corpuscles of Touch. (After Frey.) *a*, from the soft skin of the duck's bill; *b* and *c*, from the papillæ of the tongue of the same animal.

The "End-bulbs of Krause" are similar to the foregoing structures. They are small capsules of connective tissue in which nuclei can be detected, and in which the nerve-fibrils seem to terminate in a coiled mass or bulbous extremity.

The "Corpuscles of Wagner" (or Meissner) are oval-shaped bodies bearing some resemblance to a miniature fir-cone. The nerve-fibres appear like "creeping roots," to wind beneath the papillæ of the skin and, interpenetrating them here and there, to terminate in the corpuscles. Within the corpuscles, the fibrils are described as forming two or three coils and joining together in loops. Of 400 papillæ counted in $\frac{1}{60}$ inch square, on the third phalanx of the index finger, these corpuscles were discovered in 108. They are from $\frac{1}{880}$ to $\frac{1}{140}$ inch long.

Since the surface of the skin is everywhere sensitive to pressure and to temperature, but these special structures are not found everywhere, it follows that they cannot be the *sole* organs of touch. As has already been said, the free nerve-fibrils must act as the end-organs of those sensations which belong to the whole surface of the body. Research and conjecture have not yet succeeded in assigning special functions to any of the varieties of the end-organs of touch.

STRUCTURE OF THE EYE.

With the exception of the ear, the end-organ for the sensations of light and color is by far the most elaborate and complicated. It is obviously adapted to be the instrument of an intellectual and "geometrical" sense. Considered as a whole, its plan may be stated in one sentence as follows: The Eye is an optical instrument of the nature of a *water camera obscura*, with a self-adjusting lens, and a concave sensitive membrane of nervous matter, on which an image is formed. Its structure affords a practical solution of several problems. Among these the first is of a purely mechanical sort, and may be called "the problem of protection."

Coats or Tunics of the Eyeball. — Three coverings surround the eye, one of which, in part, acts also as a refracting medium. (1) The external coat consists of two parts, (*a*) the *Sclerotic* (or "white of the eye") a firm, fibrous membrane of connective tissue intermingled with elastic fibres; and (*b*) the *Cornea*, or translucent front one-sixth part, which rises and bulges in the middle like a watch-glass, and which is covered with conjunctival epithelium. (2) The second coat also consists of two parts, (*a*) the *Choroid*, which is of a dark brown color, due to the presence of pigment cells; and (*b*) the *Iris*, a circular, disk-shaped diaphragm, in the form of a lens, which is bathed with aqueous humor and has in its centre a circular aperture (the "pupil"). The anterior border around the iris consists of the *ciliary muscle* and the *ciliary processes*.

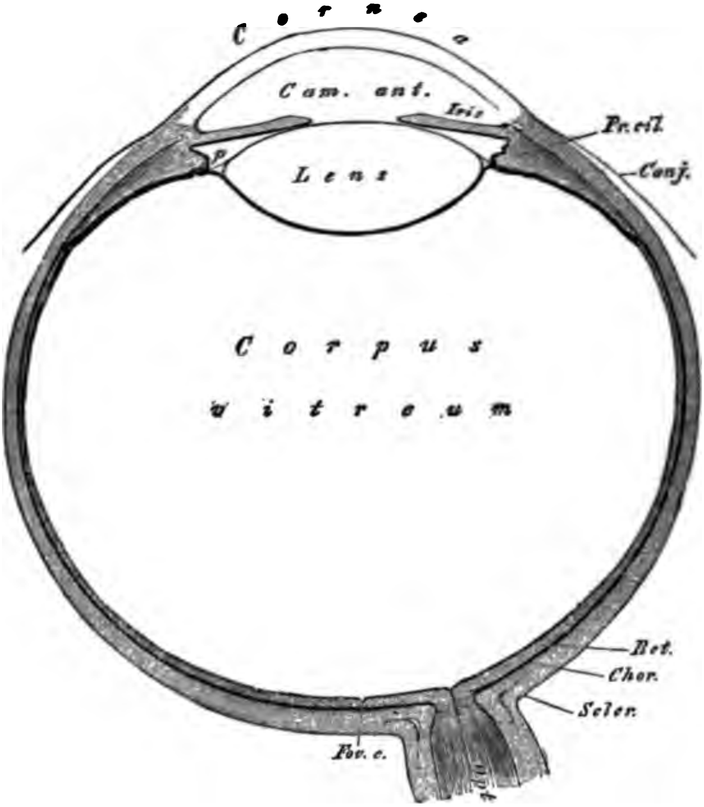

FIG. 30.—Horizontal Section through the Left Eye. $^4/_1$. (Schematic, from Gegenbaur.)

(3) The *Retina* is the third, or inner coat of the eye. It is a delicate membrane, consisting of nine or ten layers, of exquisite transparency and almost perfect optical homogeneity. Its inner surface is moulded on the vitreous body, and it extends from the entrance of the optic nerve nearly as far forward as the ciliary processes.

Refracting Media of the Eye. — The eye has four translucent refracting media. These are (1) the *Cornea*, already spoken of as the anterior one-sixth of the outer tunic of the eye. (2) The *Aqueous Humor* fills the space back of the cornea and is divided by the iris into two chambers, of which the front one is the larger. It is limpid and watery, but holds certain salts in solution. (3) The *Crystalline Lens* is situated between the iris and the vitreous body. It is transparent, biconvex, with its antero-posterior diameter about one-third less than the transverse diameter. It consists of a capsule and an enclosed body, is of "buttery consistency" and made up, like an onion, of concentric layers. (4) The *Vitreous Humor* consists of a number of firm sheets, between which fluid is contained, built into a body that is, optically considered, transparent and nearly homogeneous. It is a gelatinous form of connective tissue. Though it occupies most of the bulk of the eyeball, it has comparatively little physiological significance.

Appendages of the Eyeball. — Of the accessory parts of the eye, — eyebrows, eyelids, lachrymal glands, etc., — only the muscles have any interest to physiological psychology. Of these there are six which are attached to the eyeball, somewhat like a bridle to a horse's head. Four of these muscles spring from the bony wall near the point where the optic nerve enters, extend through the length of the socket, and pass directly to the eyeball, where they are attached to it, — one above, one below, one on the outer, and one on the inner side (the *recti*; *internal* and *external*, *superior* and *inferior*). The other two muscles of the eye are called *oblique*. The superior internal oblique, instead of running directly to connect with the eyeball, passes through a ring, then turns round, and is attached obliquely to the upper surface. The other oblique muscle begins at the inner wall in the socket, passes under the eyeball, and is attached to it opposite to the superior oblique muscle.

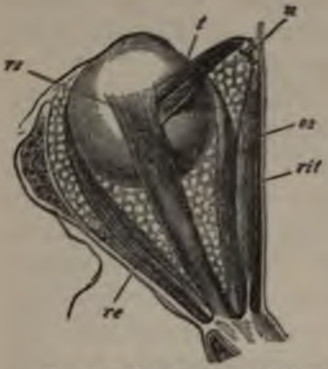

FIG. 40. — Muscles of the Left Human Eye, seen from above. *rs*, rectus superior; *re*, rectus externus; and *rit*, rectus internus; *os*, superior oblique, with its tendon *t*, which runs through the membranous pulley *u*, at the inner wall of the cavity of the eyeball.

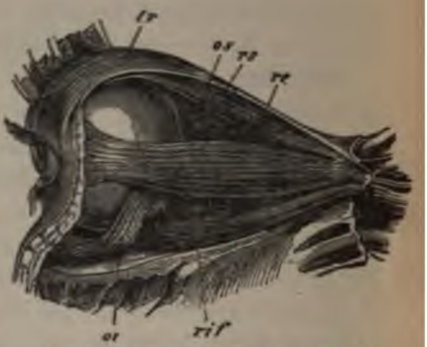

FIG. 41. — Muscles of the Left Human Eye, seen from the outside. *lr*, *levator* of the upper eyelid, which covers the rectus superior, *rs*; *re*, *os*, as in the preceding figure; *rif*, rectus inferior; *oi*, inferior oblique.

Formation of the Retinal Image. — The problem which is to be solved by the end-organ of vision, in its most general form, may be stated as follows: *A mosaic of localized sensations of light and color must be so constructed that changes in the quantity, quality, local coloring, and sequence of these sensations shall be interpreted as the size, shape, locality, and motion of external visible objects.* The most important part of the solution of this general problem falls upon the retina. And the most important problem, subordinate to the general problem, is the "formation of an image" upon the retina. But this problem is an optical one. It is solved by the translucent refracting media of the eye.

The four media of the eye constitute a system of refracting surfaces, each of which is separated from the one adjoining by a circular cut, as it were, in the whole refracting substance. Thus the "image" of the first refracting surface of this system of surfaces becomes an "object," as it were, for the second refracting surface; the second "image" an "object" for the third surface, and so on. In tracing the course of the rays through these media two things must chiefly be taken into the account. They are (1) the indices of the refraction of the refracting media, and (2) the geometrical form and position of all the limiting surfaces.

Our knowledge of the indices of the refracting media of the eye is derived by taking the average result of an examination of a number of eyes supposed to be normal. In this calculation the lens is, of course, much the most important of all the media. But the structure of the lens is such (see Fig. 42) that the index of refraction is not homogeneous throughout. Each layer has its own index, and the amount of the index of each layer increases toward the kernel of the lens. By this contrivance the entire work of refraction done by the lens is made greater than the work which could be done by a homogeneous lens with an index of refraction equal to that of its most highly

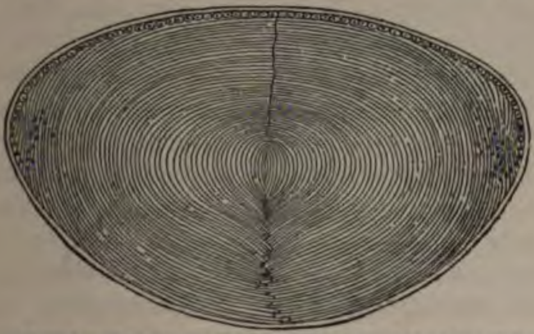

FIG. 42.—Median Section through the Axis of the Lens of the Eye. (Schematic, after Babuchin.)

refracting part. The mean index for the lens of the normal eye may be given = 1.4545. The mean index of refraction for the cornea is given at about 1.3507; of the aqueous humor at 1.3365–1.3420; of the vitreous body at 1.3382–1.3485.

The position and form of the surfaces of the refracting media can be only approximately determined. Three of these surfaces are most important, — namely, the anterior of the cornea and the two surfaces of the lens. The convexity of the anterior surface of the cornea is greater toward its edge than at its vertex, where it resembles a section of an ellipsoid. The images formed when the pupil is expanded are thus made sharper. No observable refraction takes place at the back surface of the cornea.

Accommodation of the Eye. — The ability to alter the refracting conditions of the eye for varying distances of the object is called its "power of accommodation." This adjustment obviously cannot take place like that of the photographer's camera obscura, where a considerable change can be made in the distance of the lens from the screen on which the image is formed. It is, in fact, effected by changing the convexity of the lens, — principally, if not wholly, at its *anterior* surface. This may be demonstrated by several methods of experiment. Indeed, when accommodation is taking place, the pupil may be seen to contract and to draw its edge forward. Helmholtz calculated the amount of this movement at $\frac{1}{70}$ to $\frac{1}{80}$ of an inch.

The mechanism for accommodation of the eye to varying distances of the objects must be in control of the brain, for the accommodation is voluntary; it must also consist of muscles that lie within the eyeball. The most generally accepted hypothesis of its action has hitherto been that proposed by Helmholtz. It is assumed that the lens, when at rest, is in a state of tension by its own elastic power. It is kept flattened by the radial tension of the *suspensory* *ligament* (sometimes called the *zonula*, — a structureless membranous body, interposed between the ciliary part of the retina and the vitreous humor, and radiating outward). The mechanism for withdrawing the tension consists of the ciliary muscle, the fibres of which are fixed at one end, at the edge of the cornea. When this muscle contracts, the other ends of the fibres are drawn toward its fixed ends; they thus relax the tension of the suspensory ligament by pulling in the opposite direction to this tension, and the lens is allowed to bulge out by its own elastic forces.

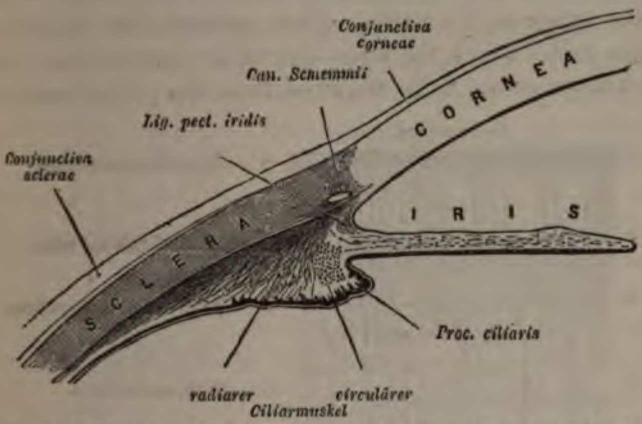

FIG. 43. Sectional View of the Connections of the Cornea, Ciliary Muscle, Ciliary Processes, etc. $^{10}/_{1}$. (Gegenbaur.)

More recent researches, however, seem to emphasize the elasticity of the vitreous body as an important factor in accommodation. For near distances, the contraction of the circular fibres of the ciliary body increases the pressure in the vitreous body, driving it into the spaces at the side of the lens, and bringing the suspensory ligament into a stronger convexity.

It is the *oculo-motor* nerve which furnishes in the posterior strands of its roots, the fibres that serve the ciliary muscle. Their place of origin is in the back part of the floor of the third ventricle. This place lies very close to that where stimulation produces contraction of the internal rectus muscle, the use of which is connected with adjustment for near distances. Thus all the mechanism of accommodation is made to work together for the production of the image on the retina. [It is assumed that the laws of optics under which the formation of the image takes place are known, or are to be acquired, from the proper sources.]

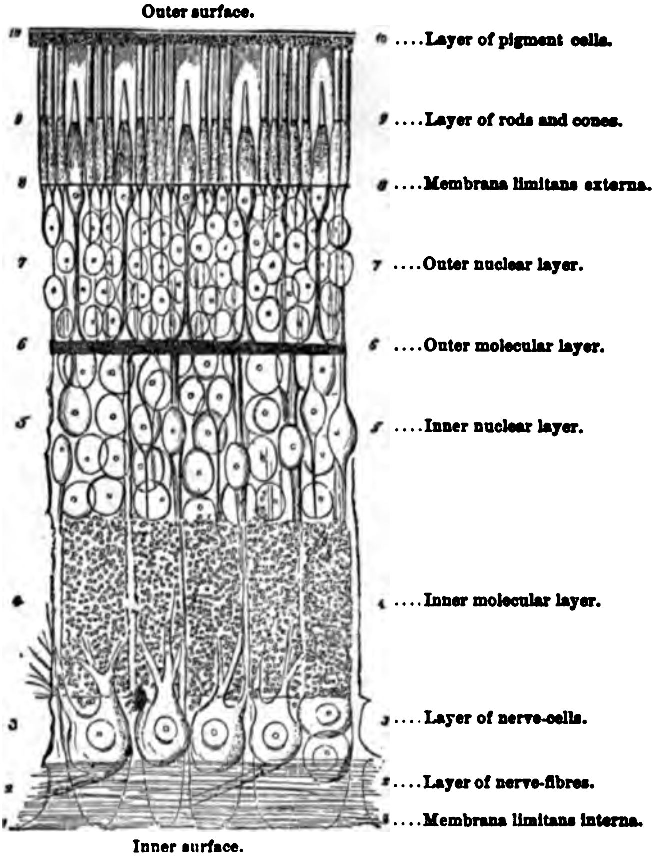
Outer surface.
10 ....Layer of pigment cells.
9 ....Layer of rods and cones.
8 ....Membrana limitans externa.
7 ....Outer nuclear layer.
6 ....Outer molecular layer.
5 ....Inner nuclear layer.
4 ....Inner molecular layer.
3 ....Layer of nerve-cells.
2 ....Layer of nerve-fibres.
1 ....Membrana limitans interna.
Inner surface.

FIG. 44. — Diagrammatic Section of the Human Retina. (Schultze.)

Given the formation of the image upon the retina, it is further required, in order to vision, that the proper physiological processes should be set up within this organ. For it is the *Retina* which contains the nervous elements by whose action the system of refracted rays is changed into a mosaic of nerve-commotions. We require then a detailed description of the structure of this wonderful organ.

Layers of the Retina. — The nervous and other elements of the retina are arranged in ten layers, — counting from within outward and backward, — the names and order of which are given in the accompanying schematic representation (see Fig. 44). By no means all the retinal substance is nervous. Numerous radial fibres, which penetrate its entire thickness, are of connective tissue, in the gaps of which the true nervous elements lie embedded. These gaps are particularly large in the second, third, fifth, and seventh layers.

Figure 45 shows (diagrammatically) the connections of the true nervous elements as they extend through the retinal layers. We notice here (*a*) the retinal fibres of the optic nerve, lying parallel to the surface. They are

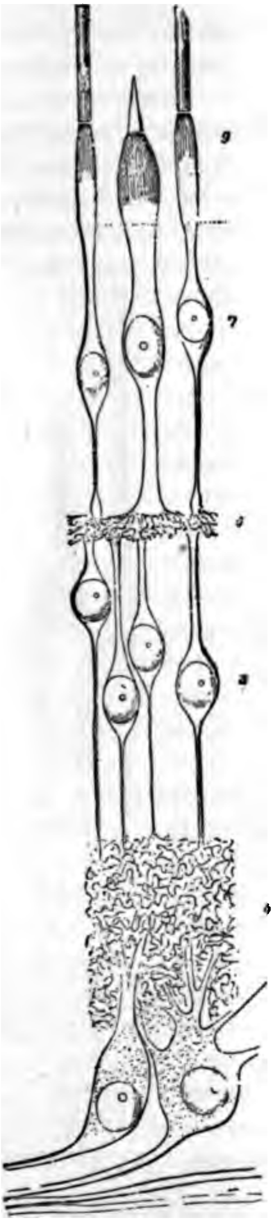

FIG. 45. — Diagrammatic representation of the Connections of the Nerve-fibres in the Retina. (Schultze.) The numbers have the same reference as in Fig. 44.

non-medullated, extremely fine, arranged in ray-like bundles, radiating on all sides from the place of entrance of the nerve. Next (*b*) come the ganglion-cells, resembling the multipolar nerve-corpuscles of the rest of the cerebrospinal system, which form the principal part of layer No. 8. These cells at the "yellow spot" are eight or ten deep, but diminish in number toward the *ora serrata*. (*c*) The nervous elements of layer No. 4 probably consist of extremely fine filaments connected with the processes of the ganglion-cells. (*d*) Each nucleus-like body in No. 5 is thought to be connected by fibres, both inward and outward. (*e*) In the outer molecular layer (No. 6) are numerous filaments of nervous character, while its star-shaped cells are probably not nervous. (*f*) In layer No. 7 are many nucleus-like bodies connected by radial fibres with the nervous elements of the rod-and-cone layer. According to their connection they are called *rod*-granules and *cone*-granules, respectively.

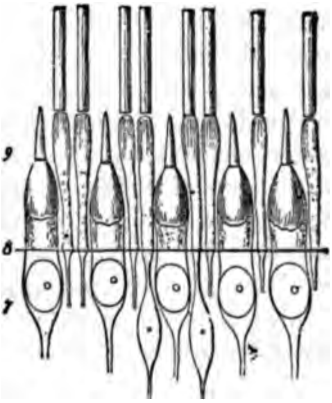

FIG. 46. — Diagrammatic Section of the Posterior Part of the Retina of a Pig. $^{800}/_{1}$. (Schultze.) 7, part of outer nuclear layer; 8, membrana limitans externa; 9, rods and cones. Each of the cones, which are in very close apposition, contains in its inner segment a highly refractile body, the function of which is unknown.

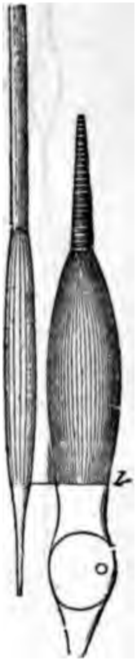

FIG. 47. — Rod and Cone from the Human Retina, preserved in perosmic acid, showing the fine fibres of the surface and the different lengths of the internal segment. $^{1000}/_{1}$. (Schultze.) The outer segment of the cone is broken into disks which are still adherent.

Rods and Cones of the Retina. — The structure of layer No. 9 is particularly interesting. It consists of a multitude of elongated bodies arranged side by side, like rows of palisades. These bodies are of two kinds, — one cylindrical, extending the entire thickness of the layer ($\frac{1}{850}$ inch long), and called "rods"; the other, flask-shaped, shorter, and called "cones." The inner ends of both bodies are supposed to be continuous with the fibres of the outer nuclear layer. Each rod, or cone, is composed of an inner and an outer segment or limb. The inner limb appears under the microscope protoplasmic, and feebly refractile. The outer limb is highly refractile. It has been thought that an extremely minute nerve-filament is drawn through the axis of these bodies. It is assumed that they are connected with the fibrils of the optic nerve by means of the retinal nerve-cells and radial fibres.

In close connection with the rods and cones stand the flat six-sided cells of the pigment-epithelium. In the centre of the eye only cones appear, which are here of more slender form and increased length; so that not less than 1,000,000 are set in $\frac{1}{10}$ inch square. Not far from the centre each cone is surrounded by a crown-shaped border of rods. Toward the ora serrata the cones become rarer.

The Yellow-spot and the Blind-spot. — The place of clearest vision, and the physiological centre of the eye, is the "yellow-spot" (*macula lutea*); it is of oval shape, about $\frac{1}{10}$ inch long, with a depression in the centre (*fovea centralis*). About $\frac{1}{6}$ of an inch interior from the middle of this spot is the place where the

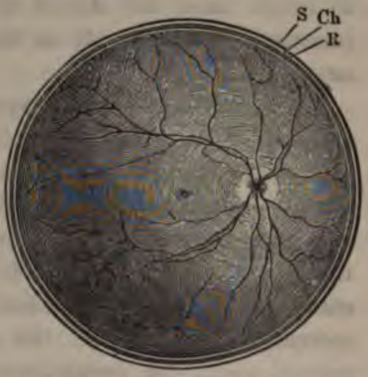

FIG. 48. — Equatorial Section of the Right Eye, showing the Papilla of the Optic Nerve, the Blood-vessels radiating from it, and the Macula Lutea. $^2/_1$. (Henle.) S, sclerotic; Ch, choroid; and R, retina.

optic nerve breaks into the retina. This place is called the "blind-spot," because it can be shown to be inoperative in vision. Its size varies considerably for different eyes ($\frac{1}{16}$ to $\frac{1}{12}$ inch long). It is wanting in all the nervous elements.

Photo-chemical Processes in Vision.— The physiological or nervous process concerned in vision can be shown to begin in the rods and cones at the back part of the retina. Indeed, by throwing a strong light through the cornea, and causing it to be reflected within the eyeball before it reaches the nervous elements of the retina (an experiment devised by Purkinje), it is possible to perceive the arborescent figure formed by the shadow of the blood-vessels expanded on the front part of our own retina. Yet the rods and cones are not directly irritable by light, so as to produce visual sensation, — at least, not unless the intensity of the stimulus be so great as to be injurious to the nervous substance itself. How, then, can we see the feeblest rays of the moon as reflected from white paper? A photo-chemical process has accordingly been assumed to result from the direct action of the light; and this process it is which acts as the immediate stimulus of the nervous elements.

Yet after many careful experiments, especially by Kühne and his pupils, it is difficult to establish the nature of the photo-chemical process concerned in vision, or of the particular pigments upon effecting changes in which the process is dependent. Any theory involves, chiefly, these two things: first, the decomposition by the light of some substance found in the epithelial elements of the retina; and, second, the action of the decomposition-products thus gained upon the protoplasm of the nervous end-organs. There seem to be decisive objections against making the *pigmentum nigrum*, or the "visual purple," or any other known pigment, the *only* substance whose decomposition by the light is necessary to vision. And as to the nature of the changes produced in the rods and cones by the decomposition-products of any pigment, we are really ignorant. A photo-chemical theory of vision seems, therefore, to be a *desideratum* rather than a scientifically established and definite fact.

The most patent thing revealed by the structure of the eye is its adaptation to serve as the organ of a highly differentiated system of intellectual and "geometrical" sensory impressions. The fuller significance of this truth cannot be understood until we have made a detailed study of those series of sensations — infinitely varied, delicately shaded, quickly successive, and speedily and firmly fusing together, as it were — which result from the activity of this organ of sense.

STRUCTURE OF THE EAR.

The End-organ of Hearing, like that of vision, so far as the principal part of its bulk is concerned, consists of mechanical contrivances for applying the stimulus to the genuine nervous elements of the special sense. The true end-organ is the mechanism of epithelial and nervous cells which is connected with the terminal fibrils of the special nerve of this sense. A brief description of the non-nervous structure is, however, desirable for our purpose.

The entire Ear consists of three parts, or ears; these are the external ear, the middle ear, or tympanum, and the inner ear, or "labyrinth," as its complicated structure causes it to be named.

I. The External Ear. — Exclusive of the plate of cartilage which projects from the side of the head, the external ear consists of two parts. These are the *concha* and the *external meatus*. (1) The concha is a rather deep hollow of a shell-like shape. It is probably of little or no use in sharpening our acoustic perceptions; although it appears to be of some service in discerning the direction of sound. (2) The external meatus is a curved passage leading from the bottom of the hollow of the concha to the drum of the ear. Its most obvious office is the protection of the ear-drum; though it may also modify certain tones by its own resonant action, — strengthening the high ones and deadening the low, in some degree.

If we place a resounding body in contact with the teeth, the intensity of the sensation of sound is much increased. This appears to us to be due to direct conduction through the cranial bones; but it is more probable that the principal path of conduction is indirect, through the ear-drum and small bones of the middle ear to the fenestra ovalis.

II. The Middle Ear, or Tympanum. — This part of the organ of hearing is an irregular cuboidal chamber, situated in the temporal bone, between the bottom of the meatus and the inner ear. Its outer wall is the *membrana tympani* or "drum" of the ear. In the inner wall, which separates it from the labyrinth, are two openings called "windows" — the *fenestra ovalis* and the *fenestra rotunda*. Near its anterior part it opens into the *Eustachian tube*. And an irregular chain of bones — called *auditory bones* — stretches across the cavity from its outer to its inner wall.

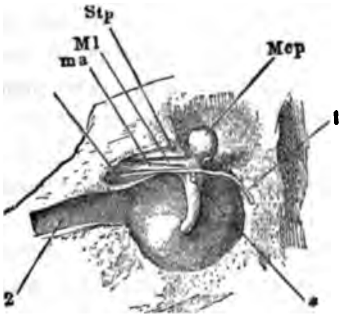

FIG. 49. — Drum of the Right Ear with the Hammer, seen from the inside. $^2/_1$. (Henle.) 1, chorda tympani; 2, Eustachian tube; *, tendon of the tensor tympani muscle cut off close to its insertion; ma, anterior ligament of the malleus; Mcp, its head; and Ml, its long process. Stp, *Spina* tympanica posterior.

The Membrana Tympani, or Drum of the Ear. — This membrane consists of three layers, — an external, and internal mucous, and the intermediate *membrana propria*. The last is the true vibrating membrane, and is composed of unyielding fibres arranged both radially and circularly.

A flat membrane, evenly stretched, whose mass is small in proportion to the size of its surface, is easily thrown into vibration by acoustic waves striking against one of its surfaces. It responds readily to tones which approach its own fundamental tone, but is scarcely at all affected by divergent tones. Such a membrane, therefore, cannot repeat a motion which consists of a series of harmonious partial tones. In order to perform such a service, a membrane must be so arranged and connected as to have no preponderating tone of its own. For this the ear-drum is prepared by two devices: (1) It is drawn inward into a funnel-shaped form by being attached to one of the auditory bones (the handle of the *malleus*); and (2) it is loaded with a chain of bones so as to have no trace of a tone of its own (see Fig. 50). Thus is secured for it the property of taking up the vibrations of a large scale of tones.

Moreover, since the apex of its funnel bulges inward, the ear-drum serves to concentrate the force of the vibrations from all sides. Loading it with the auditory bones serves also to dampen its vibrations and prevent them from continuing too long. This gives speed to the rate at which definite auditory sensations can be repeated.

The Eustachian Tube. — This opening from the middle ear into the mouth is of indirect but important physiological service to auditory sensations. In its normal position the tube is neither closely shut nor wide open. When we swallow, it opens and thus effects a renewal of air in the middle ear, maintains an equilibrium of pressure on both sides the drum, and conveys away the fluids that collect in its cavity. But if it remained constantly wide open, we should be likely to hear our own voices as a roaring sound, and the passage of the air in and out during respiration would effect the tension of the drum.

The Auditory Bones. — The chain of bones which stretches across the tympanic cavity consists of three members, — the *Malleus* ("hammer"), the *Incus* ("anvil"), and the *Stapes* ("stirrup"). The malleus has a head separated by a constricted neck from an elongated handle. The latter is attached to the centre of the membrana tympani. The incus has a body and two processes. On the front surface of its body is a saddle-shaped hollow. Its short process is bound by a ligament to the posterior wall of the tympanum. Its long process ends in a rounded projection (*os orbiculare*). The stapes has a head and neck, a base and two crura. These are put together so as to give it the stirrup-shape, which its name implies. The manner in which these bones articulate may be fairly well seen by the accompanying figure (No. 50).

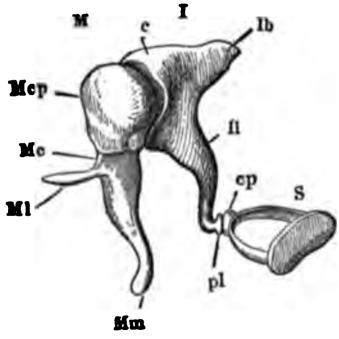

FIG. 50. — Bones of the Ear, as seen in their connection from in front. $^4/_1$. (Henle.) I, Incus (anvil), of which Ib is the short, and Il the long, process; c, its body, and pl. the process for articulation with the stapes (*processus orbicularis*). M, Malleus (hammer), of which Mc is the neck; Mcp, the head; Ml, the long process; and Mm, the manubrium; S, stapes (stirrup), with its capitulum, cp.

The auditory bones are moved on each other at their joints by two or three muscles, — especially by the *tensor tympani*. This muscle is inserted into the malleus, near the root, and serves to tighten the tympanic membrane by drawing the malleus inward. The acoustic vibrations, imparted by the membrane to these bones, are not longitudinal but transverse. They do not, however, resemble the vibrations of a stretched cord or a fixed pin. The bones vibrate as a system of light, small levers, with a simultaneous motion around a common axis. The vibrations are sympathetic, and vary greatly for tones of different pitch and similar intensity.

General Office of the Middle Ear. — By this part of the organ of hearing the acoustic waves are transmitted to the inner ear, while their character is greatly modified. Modification is necessary to prepare the stimulus for the organism of the inner ear. The waves in the air, when they reach the ear-drum, have a large amplitude but a comparatively small intensity. Their motion must be changed into one of diminished amplitude and increased intensity. But the transmitting, vibrating media must also have the power of answering to the different tones of any pitch perceptible by the ear.

III. The Internal Ear, or Labyrinth. — It is in this marvellously complex organ that the terminal fibrils of the auditory nerves are distributed and the end-organs of hearing are placed. It consists of three parts — the *Vestibule*, the *Semicircular Canals*, and the *Cochlea*. Each of these parts is, as it were, made twice over — once in the form of channels cut in the petrous bone (the *osseous* vestibule, etc.), and again in the form of a membrane (the *membranous* vestibule, etc.) suspended in the bony cavity, but only partly filling it.

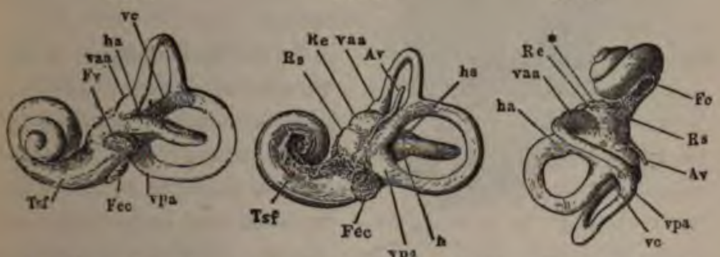
No. 1. No. 2. No. 3.

FIG. 51. — No. 1, Osseous Labyrinth of the Left Ear, from below; No. 2, of the Right Ear, from the inside; No. 3, of the Left Ear, from above. (Henle.) Av, aqueduct of vestibule; Fc, fossa of the cochlea; Fec, its fenestra (*rotunda*); Fv, fenestra of the vestibule (*ovalis*); ha, external ampulla; h, external semicircular canal; Tsf, *tractus spiralis foraminosus*; vaa, ampulla of the superior semicircular canal; vc, posterior semicircular canal; and vpa, its ampulla.

(*A*) **The Vestibule of the Ear.** — The central cavity of the inner ear, called the "vestibule," is the earliest and most constant part of the labyrinth. In its outer wall is the fenestra ovalis; its anterior wall communicates with the *scala vestibuli* of the cochlea. The membranous vestibule is composed of two sac-like dilatations — the upper and larger called *utriculus*, the lower *sacculus*.

(*B*) **The Semicircular Canals.** — These curved channels open into the utriculus. They are three in number, about one inch in length and $\frac{1}{16}$ inch in diameter. They have a regular relative position — their planes being at right angles to each other — as indicated by their names — *superior*, *posterior* or vertical, and *external* or horizontal (see Fig. 51). Near the vestibule they dilate into the so-called *ampullæ*.

Both the osseous vestibule and the osseous canals contain a fluid (*perilymph*) in which the corresponding membranous parts — themselves distended with a fluid (*endolymph*) — are suspended. The office of this fluid is very important in the transmission and further modification of the acoustic waves.

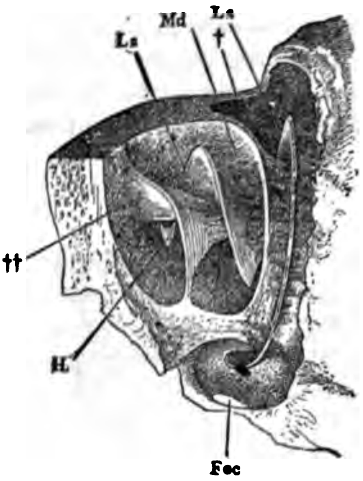

FIG. 52. — Osseous Cochlea of the Right Ear, exposed from in front. $^4/_1$. (Henle.) †, section of the division-wall of the cochlea; ††, upper end of the same; Fec, fenestra; H, hamulus; Md, modiolus; Ls, lamina spiralis.

(*C*) **The Cochlea.** — This wonderful organ is shaped like the shell of a common snail, about ¼ inch long. It, too, consists of a membranous sac in an osseous cavity. The whole passage is imperfectly divided into two canals by a partition-wall of bone (the *lamina spiralis*), which winds 2¼ times around an axis (the *modiolus*), like a spiral staircase.

Of these canals, the one which faces the base is called *scala tympani;* the other, which opens into the vestibule is the *scala vestibuli.* At the apex they communicate through a small hole (the *helicotrema*). From the free edge of the spiral lamina to the outer wall the interval is bridged over by the *basilar membrane.* Still another membrane (*membrane of Reissner*) arises from a crest attached to the same lamina and extends to the outer wall, so as to make a minute canal between itself and the basilar membrane. In this canal — called *scala intermedia,* or *ductus cochlearis,* or "canal of the cochlea" — the nervous end-organs of the cochlea are found.

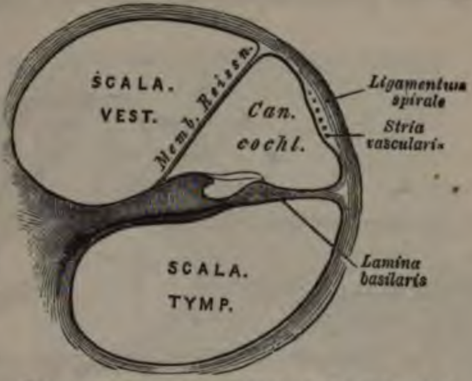

FIG. 53. — Section through one of the Coils of the Cochlea. $^{20}/_{1}$. (Schematic, from Gegenbaur.)

The Organ of Corti. — On that surface of the basilar membrane which is directed toward the small canal of the cochlea is placed a structure which consists of a wonderful arrangement of cells. Some of these cells are curved, elongated, and placed in two groups — an inner and an outer (*rods,* or *fibres of Corti*). The two are arranged (as shown by Fig. 54) so as to make a *bow* or arch over an exceedingly minute canal (*canal of Corti*) between them and the basilar membrane. These rods of Corti increase in length from the base to the apex of the cochlea. Each rod rests upon one or two of the transverse fibres of the basilar membrane. The Organ of Corti is separated from the endolymph of the ductus cochlearis by the so-called *membrana tectoria.* (For the shape and position of the "hair-cells," inner and outer, the supporting cells, etc., see the accompanying diagrammatic representation.)

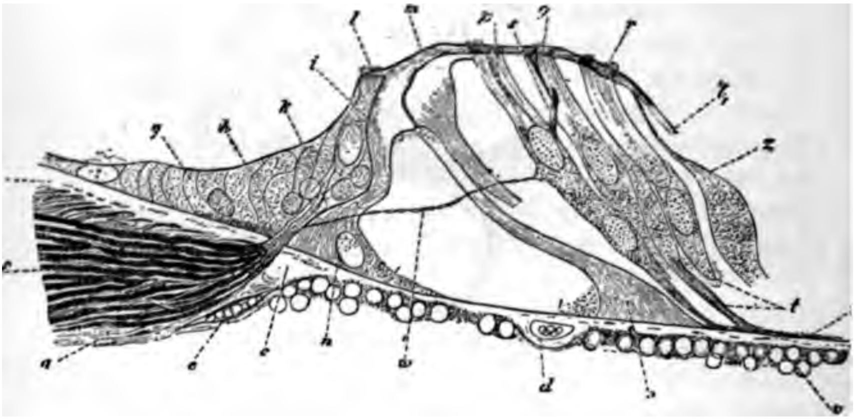

FIG. 54. — Organ of Corti in the Dog. $^{800}/_{1}$. (Waldeyer.) *b—c*, homogeneous layer of the basilar membrane; *u*, its vestibular layer; *v*, its tympanal layer; *d*, blood-vessel; *f*, nerves in spiral lamina; *g*, epithelium of spiral groove; *h*, nerve-fibres passing toward inner hair-cells *i*, *k*; *l*, auditory hairlets on inner hair-cells; *l—l*, lamina reticularis; *m*, heads of the rods of Corti jointed together; the inner rod seen in its whole length; the outer one broken off; *n*, cell at base of inner rod; *p*, *q*, *r*, outer hair-cells; *s*, a cuticular process probably belonging to a cell of Deiters; *t*, lower ends of hair-cells, two being attached by cuticular processes to the basilar membrane; *w*, a nerve-fibril passing into an outer hair-cell; *z*, a sustentacular cell of Deiters.

Distribution of the Auditory Nerve. — The auditory nerve, on approaching the labyrinth, divides into several portions. In the vestibule, branches are distributed to the utriculus, the sacculus, and each of the three ampullæ. In a ridge in the wall of each of these dilatations (the *crista acoustica*) columnar and fusiform cells are found, with processes from the latter of which the fibrils of the auditory nerve are brought into connection, — probably by means of that minute network of fibrils with which we have already become familiar in the other end-organs of sense. The so-called "auditory hairs" are found by recent observers to be connected with the columnar cells; they form, on the inner surface of the epithelium of the ridge a "thick-set wood." Calcareous particles exist (the *otoliths* or "ear-stones") in both saccule and utricle, lying embedded in contact with the nerve-epithelium.

The cochlean branch of the auditory nerve pierces the modiolus and gives off lateral branches which pass into channels in the osseous spiral lamina. Here the fibres radiate to the membranous lamina and are connected with a ganglion of cells. Beyond this ganglion they lose their medullary sheath, and become extremely fine axis-cylinders, the delicate fibrils of which are probably connected with the nerve-plexus of the fibrils from the cone-cells of the organ.

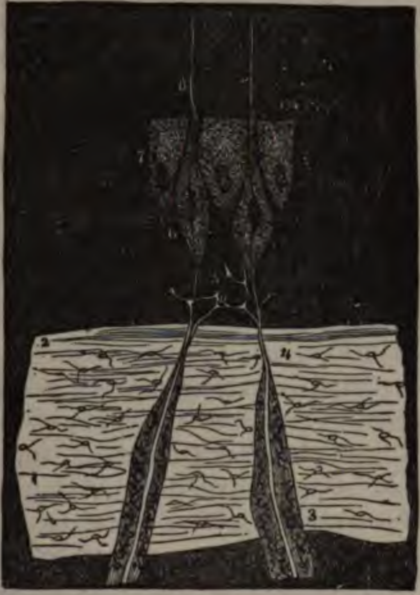

FIG. 55. — Scheme of the Nerve-endings in the Ampullæ. (After Rüdinger.) 1, membranous wall of the ampullæ, with a structureless border 2, through which the nerve-fibre 3, sends its axis-cylinder 4; 5, plexiform connection of the nerve-fibres; 6, auditory cells; 7, supporting cells; 8, auditory hairs.

Special Office of the Labyrinth. — The greater bulk of the inner ear, like the whole of the other principal parts, is used to transmit and modify the acoustic waves. We have seen that the membranous labyrinth is filled with, and suspended in, a fluid medium. Molecular oscillations of this fluid can scarcely, however, serve as the direct stimulus of the nerve-elements. Its dimensions are so very small in comparison with the length of the acoustic waves as transmitted by the shocks of the stirrup at the fenestra ovalis, or the pulsations of air at the fenestra rotunda, that the movement of the entire fluid mass would be practically instantaneous. Several places may be pointed out, however, into which the waves of the fluid could retreat, by the membranes yielding, or by itself running into pores and through the passages connecting the various parts. The friction of these movements back and forth, especially when increased by the action of the otoliths, might thus irritate the nerve-elements. The basilar membrane would undoubtedly be thrown into vibration by the unequal pressure of the fluid, and thus the nervous structures situated upon it might be irritated. In all this, however, much is still a matter of doubtful conjecture.

A still more difficult question to answer is this: How does the ear manage to *analyze* the acoustic influences? This organ plainly is not contrived so as to reproduce changes in the form of acoustic oscillations in such manner that these changes can be made apparent to the eye or to touch. But our experience with "clangs," or the musical notes of ordinary kind, seems to require that we should find in the ear some sympathetic vibratory apparatus. Such apparatus must suffice for all kinds of *noises*, and for all *musical tones*, and for simultaneous hearing of several tones as *harmony*, and for so rapid a succession of different sensations as occurs when we hear a melody, or even the crackling of an electric spark at intervals of 0.002 sec.

It has been for some time commonly assumed that the vestibule and semicircular canals are the organs for hearing noises, and the cochlea for hearing musical sounds. This differentiation of function is certainly suggested by the marked differences in the structure of their parts. The otoliths and hairs of the former do not seem adapted for regular sympathetic vibrations. The rods of Corti and radii of the basilar membrane suggest that *here* is the apparatus needed for acoustic analysis.

Recent investigations, however, tend to show that the physiological distinction between noises and sounds will not hold with sufficient rigor. The two seem to pass into each other by insensible gradations. It has been found possible to make a series of sharp noises, like a watchman's rattle, as often as 600 times per second, without producing a musical tone, if all extra accompanying sounds are completely dampened. On such grounds it has been concluded that we hear noises and tones with the same organ.

It was first argued by Helmholtz that the fibres of Corti — some 3000 in number and arranged in rows on the basilar membrane like the keys of a piano-forte — are just suitable for the required sympathetic vibrations. But these rods are stiff and not easily vibratory, and their office seems to be that of supporting the hair-cells. Birds, moreover, can appreciate musical notes but have no rods of Corti. It has therefore been proposed by Hensen and others to regard the radii of the basilar membrane as themselves graded to pitch. These radii, by moving up and down, might excite the conical hair-cells, whose number is supposed to be about sufficient to satisfy the demands of musical analysis. More recently still, it has been conjectured that, since the arches of Corti at the base of the cochlea are small and little spread, and those at the upper end are larger and much spread, the size and the shape of these structures may approximately compensate each other; this would make it possible for all of the arches to vibrate to each of the fibres of the basilar membrane (like the sounding-board of a piano).

We are obliged to confess that our knowledge of the minutest structure of the ear, and especially of the manner in which it performs its functions, is exceedingly fragmentary. As one principal investigator remarks: "It is possible that the working of this apparatus may be altogether different from any of our present conjectures."

END-ORGANS OF MOTION.

The motor nerves of animals have their peripheral connection with either electrical organs, or secretory glands, or muscular fibre. A very brief consideration of the last case, only, will suffice for our present purpose.

After a motor nerve has entered the substance of the so-called voluntary or striated muscle it breaks up into nerve-twigs between the muscular fibres. The axis-cylinders of the nerve-twigs lose their medullary sheath, and subdivide into fibrils, which form a flat branching mass within certain disk-shaped bodies inside the sheath of the muscle-fibre (the *sarcolemma*). These bodies are the so-called "motor end-plates." In the non-striated (or non-voluntary) muscles, the nerves subdivide into very minute plexuses of nerve-fibres, which are distributed in the connective tissue that separates the muscular fibres.

The shape and structure of the motor end-plates are different for different animals, and even for different muscles of the same animal. The mode of the termination of the nerve in the muscle is thought to be somewhat distinctive of the different parts of the muscular structure. Sometimes the axis-cylinders are enlarged, with granular corpuscles attached or adjacent. Sometimes a granular mass, with its nuclei, forms a kind of floor for the terminal nerve-fibres; and this eminence may be either elongated, elliptical, or circular.

CHAPTER IV.

DEVELOPMENT OF THE NERVOUS SYSTEM.

IN that living germ, in which the life of the individual human being originates, there is no apparent distinction of bodily organs, or of physical and psychical activities. To scientific observation this germ seems "undifferentiated." But it undergoes a development, and before it can be subjected to ordinary observation it has unfolded itself into an elaborate organism. The course of this development can be traced, in man's case, only very imperfectly by even the most patient embryological investigation.

Fortunately, however, the very first things in the life of the other mammals, and even of the chick (the most convenient subject of study for embryology) are in most important respects similar to those of man's earliest development. This knowledge, indirectly derived, is constantly being more and more supplemented by direct microscopic inspection of the human embryo, at various stages in its life. Thus a sketch of the principal outlines of man's pre-natal evolution is made possible. A few points selected from such a sketch, and having reference especially to the nervous system, furnish helpful suggestions with regard to certain questions in physiological psychology.

EARLIEST DEVELOPMENT OF THE BODILY LIFE.

The following brief description of the earliest development of the animal body is chiefly taken from the detailed embryology of the common fowl.[1]

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[1] For further study of this subject, Foster and Balfour's Elements of Embryology, London, will probably be found most accessible and serviceable.

The Ovarian Ovum. — The immature egg (ovarian ovum) of any animal presents the characters of a simple cell. It appears as a naked protoplasmic body containing in its interior a nucleus (*germinal vesicle*), and within this a nucleolus (the *germinal spot*). It is enclosed in a capsule of epithelium called the “follicular membrane.” The principal difference between the ovum of a mammal and that of a bird consists in the amount and distribution of the food-yolk. The human ovarian ovum is only $\frac{1}{150}$ to $\frac{1}{125}$ inch in diameter, because it contains so little food-yolk; but this small supply is uniformly distributed.

As the ovum matures, its body grows in size, and granules appear in the interior. As these earliest granules enlarge, others appear at the periphery. The germinal vesicle travels toward the surface, and accessory germinal spots make their appearance. The cells of the follicular membrane — at first a single row — now become two or three deep. The superficial layer of the ovum is converted into a striated membrane. Between this and the cells of the follicular membrane another membrane (the *vitelline*) afterward appears. The striated membrane disappearing, the vitelline remains alone. But the essential constituent of the body of the ovum is an active, living protoplasm.

Impregnation and Segmentation. — The spermatozoon, or male fecundating element, may itself be considered as a cell, the nucleus of which is its head. *Impregnation* takes place by the entrance of a spermatozoon into the ovum, followed by the fusion of the two. On entering, the substance of the tail of the spermatozoon mingles with the protoplasm of the ovum, while the head enlarges and also fuses with a portion of the ovum, thus constituting the nucleus of the impregnated egg. In this actual fusion of substance derived from both parents, provision is made that the offspring shall partake of the physical and psychical characteristics of the two.

Segmentation, or "yolk-cleavage," follows fecundation of the ovum. This process consists in dividing the ovum into a number of cells from which all the cells of the full-grown animal are the lineal descendants. The germinal disk of the ovum is thus broken up into a large number of rounded segments of protoplasm, called the *blastoderm.* The upper segments being smaller than those beneath, the beginning of two layers is thus made. This distinction is then made more obvious by the segments of the upper layer arranging themselves side by side into a membrane of columnar, nucleated cells; but the segments of the lower layer continue granular, and form a close, irregular network of cells.

As the process of segmentation goes on, the differences among the ova of different species of animals become more clearly marked. The mechanical explanation of this is, in part at least, the difference in the amount and distribution of the food-yolk.

The Blastodermic Vesicle. — A narrow cavity now appears between the two layers of the ovum, which soon extends so as to separate them completely, except in the region near a small circular area. In this area the inner mass of the ovum has remained longer than elsewhere exposed, before the outer cells closed over it. The enlargement of the ovum, and of the cavity between the layers, gives the whole structure the appearance of a vesicle with a thin wall. It is therefore now called the *blastodermic vesicle.* Its walls are for the most part composed of a single row of outer flattened cells; while an inner lens-shaped mass of cells appears attached to a portion of the inner side of the outer layer. As the vesicle grows rapidly, this inner mass becomes, on the whole, flattened so as to spread out on the inner side of the outer layer. But its central part remains thick, and forms an opaque spot, which is the beginning of the area where the embryo is to form (*the embryonic area*).

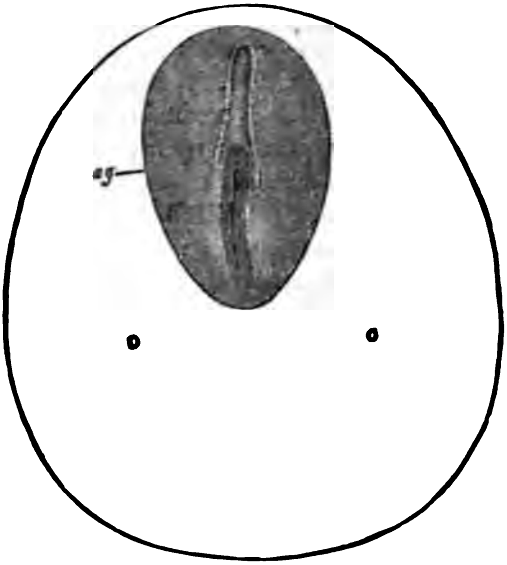

FIG. 56. — Vascular Area and Embryonic Area of the Embryo of a Rabbit, seven days old. $^{28}/_{1}$. (Kölliker.) *o*, *o*, the vascular or opaque area; *ag*, embryonic area; *pr*, primitive streak and groove; *rf*, medullary groove.

The Three Layers of the Embryo. — In the area just described there are first formed two distinct strata. Of these, the upper one consists of rounded cells, which lie close to, and become fused with, the flattened outer layer; it is then called *epiblast*. The lower one consists of flattened cells, and is called *hypoblast*. We have thus a double-walled sac (the *gastrula*). Between these two strata, or layers, a third soon makes its appearance; from its position it is called *mesoblast*.

These three layers are found in the embryo of all vertebrate, and of most invertebrate, animals; and from them all the different parts of the animal organism are developed. The history of the life of every animal, thus constituted, is in its earlier stages a history of the evolution of these layers. The hypoblast is the secretory layer; and from it almost all the epithelial lining of the alimentary tract, and of its glands, is derived. From the mesoblast come the skeletal, muscular, and vascular systems, and the connective tissue of all parts of the body. But it is the development of the epiblast which most concerns us. For from it is evolved the central and peripheral nervous system, the epidermis, and the most important parts of the organs of sense.

From the beginning, then, the skin in which the end-organs of touch and of the other sensations are situated, as well as all the organs of special sense, constitute, with the brain and spinal cord, one interconnected mechanism.

DEVELOPMENT OF THE NERVOUS SYSTEM.

The process of differentiating the layers of the blastoderm is intimately connected with another, in which the foundations, as it were, of the nervous structure are laid. This is —

The Formation of the Medullary Groove. — A short sickle-like thickening, due to a forward propagation ("linear proliferation") of epiblastic cells in a straight line, occurs near the junction between the pellucid and the opaque areas, and stretches inward upon the embryonic area. It is called the *primitive streak*. Its middle line then shows

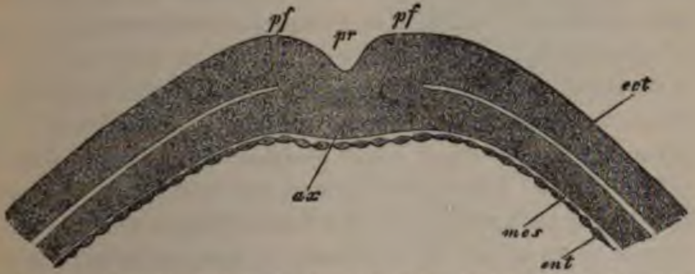

FIG. 57. — Primitive Streak of the Embryo of a Rabbit, eight days and nine hours old. $^{20}/_{1}$. (Kölliker.) No medullary groove has yet been formed. *ax*, primitive streak; *pr*, primitive groove; *pf*, primitive fold; *ect*, ectoderm (or *epiblast*); *mes*, mesoderm (or *mesoblast*); *ent*, entoderm (*hypoblast*).

a shallow furrow called the *primitive groove* (see Fig. 57). In the embryonic area, to the front of the primitive streak, the axial part of the epiblast thickens; two folds arise along the boundaries of a shallow groove; the folds meet in front but diverge behind, enclosing between them the front part of the streak. These are the *medullary folds*,—the first definite features of the embryo.

The part enclosed between the medullary folds is called the "medullary plate"; it is the portion of the epiblast which gives rise to the central nervous system.

The Notochord and the Neural Canal.—Meanwhile an important change has taken place in the hypoblast, in front of the primitive streak. An opaque line has appeared, running forward from the front end of the streak, and stopping short at a semicircular fold near the front part of the pellucid area. This opaque line is a concentration of cells in the form of a cord,—the so-called *Notochord*. Changes in it are to give rise to the distinctively vertebral structure of the animal. The fold is the future head-fold.

And now a portion of the blastoderm in the pellucid area, heretofore nearly flat, is "tucked in," with the form of a crescent. Looked at from above, this tuck appears as a curved line along the margin of the medullary groove. Thus the blastoderm becomes at this spot folded in the form of the reversed letter Ƨ (the "head-fold" already referred to). The upper limb of the fold grows forward, the lower backward. As the fold enlarges, the crescentic groove deepens and its overhanging margin rises above the level of the blastoderm.

Meanwhile the medullary folds increase in height and lean over toward the middle line. They soon come into contact in the brain-region, although they do not at once coalesce. They thus form a tubular canal, called the *Neural* (or medullary) *canal*. By the closing of the folds in the head-region, the open medullary groove has now become converted into a tube, which is closed in front but remains open behind.

Formation of the Cerebral Vesicles. — The front end of the neural canal has a more rapid growth than the rest. It swells into a small bulb or vesicle, whose cavity is continuous with the neural canal, while its walls are formed of the epiblast. This bulb is the first "brain-bud," or *cerebral vesicle.* From its sides the processes of the optic vesicles soon grow out. Behind the first vesicle a second, and behind the second a third, is soon formed. Thus there come to be three brain-buds, or germinal brains. From them are to develop the fore-brain, the mid-brain, and the hind-brain.

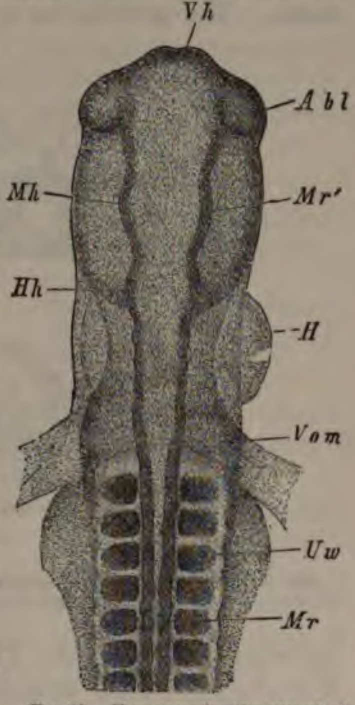

FIG. 58. — Fore-part of an Embryo-chick at the end of the second day, viewed from the Dorsal Side. $^1/_{70}$. (Kölliker.) *Vh*, fore-brain; *A b l*, ocular vesicles; *Mh*, mid-brain; *Hh*, hind-brain; *H*, part of the heart seen bulging to the right side; *V o m*, vitelline veins; *Mr*, medullary canal, spinal part; *M r'*, medullary wall of the mid-brain; *U w*, proto-vertebral somites.

Flexure of the Neural Canal. — The fore-brain vesicle, or front part of the neural canal, becomes bent downward through inequalities of growth. By increase of this flexure the front portion is folded down so that the second vesicle, or mid-brain, projects in front of it.

All the subsequent development of the nervous system is connected with the growth of the three cerebral vesicles and the flexure of the neural or medullary canal.

Development of the Cerebral Vesicles. — From the front part of the fore-brain the vesicles of the cerebral hemispheres swell out. Each of these lateral brain-buds has a cavity which is continuous with the cavity of the fore-brain. The cavities on either side become the lateral ventricles of the brain. The original vesicle of the fore-brain, having ceased to occupy its front position, develops into the parts around the third ventricle. The front portion of the third cerebral vesicle is now marked off by a constriction; thus the hind-brain is separated into two parts, — the rudimentary cerebellum with the pons in front, and the rudimentary medulla oblongata.

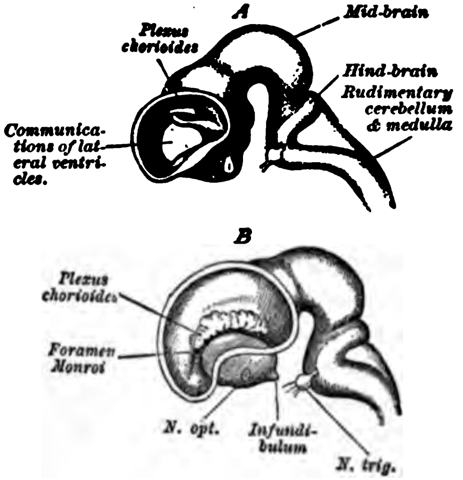

FIG. 59. — *A*, Brain of an Embryo of the Rabbit. *B*, Brain of an Embryo of the Ox. In both cases the side-wall of the left hemisphere is removed. (After Mihalkovics.)

The following table — taken from the ninth edition of Quain's Anatomy, exhibits the relation in which the developed parts of the brain stand to its fundamental rudiments: —

I. Anterior Primary Vesicle.	1. Prosencephalon, Fore-brain,	Cerebral Hemispheres, Corpora Striata, Corpus Callosum, Fornix, Lateral Ventricles, Olfactory Bulbs.
	Thalamen-cephalon, 2. Inter-brain,	Thalami Optici, Pineal Gland, Pituitary Body, Third Ventricle, Optic Nerve (primarily).
II. Middle Primary Vesicle.	Mesencephalon, 3. Mid-brain,	Corpora Quadrigemina, Crura Cerebri, Aqueduct of Sylvius, Optic Nerve (secondarily).
III. Posterior Primary Vesicle.	4. Epencephalon, Hind-brain.	Cerebellum, Pons Varolii, anterior part of the Fourth Ventricle.
	Metencephalon, 5. After-brain.	Medulla Oblongata, Fourth Ventricle, Auditory Nerve.

The Cranial and Spinal Nerves.—Along the cerebro-spinal cavity—formed as described above—various changes in the lining of the epiblast take place. This lining is thickened at the side so that the cavity comes to resemble a narrow vertical slit. The sides and floor of the canal of the cerebral hemispheres are also much thickened. But in the region of the third and fourth ventricles the roof of the canal becomes very thin.

The cranial nerves spring out of a band, composed of two plates, which connects the dorsal edges of the neural canal with the external epiblast. The fusing of the two plates makes the band into a crest on the roof of the brain. As the roots of the cranial nerves grow centrifugally and become established, the connecting crest is partially obliterated. In its earliest stages a cross-section of the brain-tube is essentially like the spinal cord in its internal structure. The region of the medulla leads the others in the development of the nerve-paths.

In the spinal cord. the posterior roots of the nerves appear as out-growths of a series of median cell-processes on the back side of the cord. Recent discoveries indicate that the motor-nerves of the cord, as well as of the brain, arise from the fundamental plate.

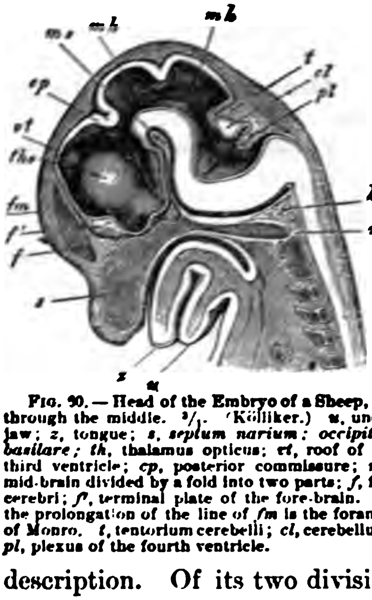

FIG. 60. — Head of the Embryo of a Sheep, cut through the middle. $^{3}/_{1}$. (Kölliker.) *u*, under jaw; *z*, tongue; *s*, *septum narium*; *occipitale basilare*; *th*, thalamus opticus; *vt*, roof of the third ventricle; *cp*, posterior commissure; *mh*, mid-brain divided by a fold into two parts; *f*, falx cerebri; *f'*, terminal plate of the fore-brain. At the prolongation of the line of *fm* is the foramen of Monro. *t*, tentorium cerebelli; *cl*, cerebellum; *pl*, plexus of the fourth ventricle.

Development of the Anterior Portions of the Brain. — Further details concerning the later changes in the hind-brain and mid-brain may be omitted. But the fate of the anterior portion of the cerebro-spinal substance requires a brief further description. Of its two divisions (see the Table, p. 111), the posterior (*thalamen-cephalon*), is at first a simple vesicle, formed of spindle-shaped cells with walls of nearly uniform thickness. Its floor gives rise to the optic chiasm and the optic nerves; its sides become thickened into the optic thalami; its roof gives rise to the pineal gland and surrounding structures.

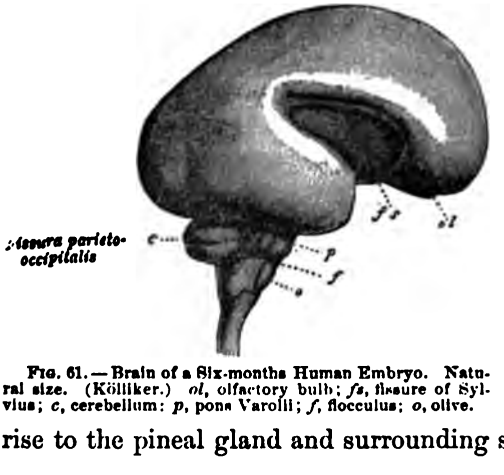

FIG. 61. — Brain of a Six-months Human Embryo. Natural size. (Kölliker.) *ol*, olfactory bulb; *fs*, fissure of Sylvius; *c*, cerebellum; *p*, pons Varolii; *f*, flocculus; *o*, olive.

The larger portion of the development from the anterior primary vesicle constitutes the rudiments of the cerebral hemispheres. Here a floor and a roof must be distinguished. The former develops into the striate bodies by the thickening of its walls. The latter forms the hemispheres proper.

One principal characteristic of the mammals is the early enlargement of the cerebral hemispheres. In the human embryo they are even by the tenth week much larger than all the rest of the brain. They grow from before backward and thus cover up, one after the other, the optic thalami, corpora quadrigemina, and cerebellum. This physical evolution is indicative of the future intellectual superiority and intellectual growth of the human being. We have already seen how early and significant is the formation of the most important convolutions and fissures. By the end of the seventh month of embryonic life, the principal features of the cerebral hemispheres are already definitely fixed.

Development of the Eye.—Lateral growths of the brain-buds, called the "optic vesicles" (see p. 109), give rise to the nervous parts of the eye. These vesicles are originally connected with the sides of the first cerebral vesicle by short and wide stalks; they then stand at nearly right angles to the embryo. The stalks become narrow and form the rudiments of the optic nerves. At the same time the rudiments of the retina are formed from the vesicles themselves.

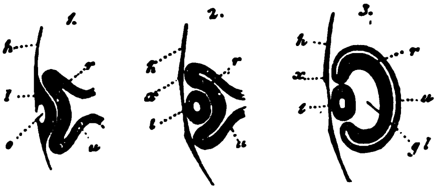

FIG. 62.—Longitudinal Sections of the Eye of an Embryo, in three stages. (From Remak.) 1, commencement of the formation of the lens *l*, by depression of a part of *h*, the corneous layer; *u*, *r*, the primitive ocular vesicle is doubled back on itself by the depression of the commencing lens. 2, the depression for the lens is now enclosed, with the lens beginning to be formed on the inner side; the optic vesicle is more folded back. 3, a third stage, in which the secondary optic vesicle *g l* begins to be formed.

The bulb of the optic vesicle is then made into a cup by doubling it upon itself. The lens of the eye is formed by thickening some of the superficial epiblast and involuting it inward over the front of the optic cup (see Fig. 62). This involution has at first the form of a pit; then of a closed sac with thick walls; then of a solid mass. The subsequent development of the eye depends upon the fact that the walls of the optic cup grow more rapidly than does the lens, and that their growth does not take place equally in all portions of the cup.

The different layers of the retina are formed by differentiations of the anterior wall of the hind portions of the optic cup. Here the cells multiply rapidly, and undergo important changes while the wall is thickening. In its early development this wall resembles the brain in its structure. It may, indeed, be considered as a part of that organ.

Development of the Ear. — The organ of hearing originally appears on either side of the hind-brain as an involution of the external epiblast, sunk in a mass of mesoblast. It is then shaped as a shallow pit with a wide-open mouth. As the mouth closes up, the pit becomes a vesicle, the *otic vesicle*. The walls thicken, and the cavity enlarges. Its shape becomes triangular, with the apex of the triangle directed inward and downward. This apex is elongated into the cochlear canal. Part of the vesicle is stretched out into a long narrow process (*recessus vestibuli*), and from the wall of the main body protuberances grow which become the vertical semicircular canals. Other protuberances are stretched out and curved into other parts of the organ.

The cochlear canal is further elongated and curved. When it has reached two and a half coils, the thickened epithelium of its lower surface forms a double ridge, from which the *Organ of Corti* is developed.

Histogenetic Development of the Nervous System. — All the coarser differentiations of structure which have been described are but the expression, as it were, of secret and exceedingly minute changes, called "histogenetic." Delicate threads of nervous tissue have been laid down, and nerve-cells have been propagated (*proliferated*) along definite lines. The white matter of the spinal cord first appears in four patches at the front and back of either half. The individual fibres appear like small dots in these patches. The gray matter is formed by differentiation of the principal mass of the walls of the medullary canal. The outer cells lose their epithelial character, and become converted into true nerve-cells, with nerve-fibres as prolongations. The nerve-fibres remain for a considerable time without the medullary sheath.

The early histogenetic development of the brain back of the cerebral hemispheres is very like that of the spinal cord. In the floor a superficial layer of delicate nerve-threads is early formed. In the fore-brain the walls of the hemispheres become divided into two layers, the inner of which unites with the fibres of the crura cerebri to give rise to most of the white matter of the hemispheres. The outer layer of rounded cells becomes further differentiated, the deeper part, with its multiplication of numerous cells, forming the principal mass of the gray matter of the cortex.

Thus does the impregnated ovum, by a process of evolution, become developed into that wonderful complexity of organs which constitutes the body of the human child. Of the correlated psychical development of the embryo little or nothing of a scientific character can be known. But the physical process by which the nervous mechanism comes into being is, nevertheless, suggestive for the student of physiological psychology. To some of the conjectures and speculations which legitimately follow from our still meagre knowledge of human embryology, we shall return at another time.

CHAPTER V.

GENERAL PHYSIOLOGY OF THE NERVES.

THE question, *What can Nervous Substance do?* naturally follows the consideration of its chemical and formal constitution. An answer to this question, however, cannot be gained by inference from our knowledge of the anatomy and histology of the nervous system. It is only by indirect processes of observation and experiment, combined with no little conjecture, that even the beginnings of a clear scientific conception of the functions of this system can be found. The attainments of science on this subject may conveniently be stated under two heads, preceded by a brief introduction. We consider then, first, certain modes of activity belonging to all nervous matter as such; and, second, — with more of detail, — the "Nerves as Conductors," and the "Automatic and Reflex Functions of the Central Organs."

Functions of the Nervous Elements. — Nerves and nerve-cells have certain properties in common; within certain limits both can do the same things. These properties may perhaps be summed up in the two words *Excitability* (or "irritability") and *Conductivity.* Both are capable of becoming, under the action of stimuli, the subjects of a specific kind of molecular motion called "neural." When stimulated or irritated, they originate, as a unique function, the process which may be called "nerve-commotion." But both nerve-fibres and nerve-cells can also propagate this peculiar kind of molecular agitation from point to point; they can conduct nerve-commotion.

Nerve-commotion is never, of course, an uncaused event. The causes that excite or irritate the nervous elements to exercise their peculiar function are called "*stimuli*." Stimuli are of two kinds, external and internal. The former comprise all such modes of energy as excite nerve-commotion by acting on the peripheral parts of the nervous system, — the terminal nerve-fibrils or end-organs of sense. Internal stimuli act directly upon the substance (nerve-cells) of the central organ; they consist in general of changes in the blood-supply, — increased or decreased oxygen, presence of drugs, etc.

General Office of the Nervous System. — In all forms of animal life, except the lowest, the action of the nervous system constitutes a chief characteristic of their difference from all forms of plant life. Plants as well as animals have contractile tissue; but the former never have nervous tissue, not to say, a nervous system. The unique functions of this system, as possessed by all the higher animals, can perhaps best be summed up in the one word, "concatenation." The linking, or *chaining together* — as it were — of distant and different physical organs and systems, and of the action of the other parts of the body with the phenomena of psychical life, is the unique function of the nervous mechanism.

In the plant, for example, every part acts directly and slowly upon contiguous parts only, for the effecting of those changes upon which its life and growth depend. But in the case of the animal, by the mediation of the nervous system, an effect produced in one part of the body may make itself quickly felt in every other part. A draught of cold air, for example, strikes some portion of the surface of the body. Immediately, the heart and lungs modify their action; the muscles contract; the secretions are disturbed; a shudder runs through the body; and perhaps the mind is seized with a vague feeling of fear. Thus changes which involve the tissues and functions of almost all the organs of the body are accomplished by the mediation of the nervous system.

MORE PARTICULAR FUNCTIONS OF ALL NERVES.

We have already seen (p. 32 f.) that the plan on which the nervous system develops leads to a threefold economy of organs. In this threefold economy, the office of conducting the nerve-commotion between the end-organs and the central organs has been assigned especially to the *nerves*. The function of conducting neural molecular agitations belongs, indeed, as an essential function, to all nervous substance. But the nerve-fibres, as bound together into nerves, possess, in all normal conditions of the nervous system, this office pre-eminently. Moreover, it is only as exercised by the nerves that the laws of neural conduction can be at all satisfactorily examined by direct experiment.

Physiological Distinctions in the Nerves. — If we considered only the different effects produced by conducting nervous processes along the different nerves, we should be compelled to divide the nerves into a variety of classes. In this way it has been proposed to distinguish "nerves of motion," "nerves of inhibition" (or check upon the action of other nerves), "nerves of secretion," "nerves of nutrition" (trophic nerves), "centripetal nerves that have no sensory function," and "sensory nerves," whose irritation may result in conscious sensation.

The question arises at once, however, whether the different obvious results which follow irritating all these nerves are due to real differences in the functions of the nerves themselves, or to differences in the structures and connections where the nerves terminate. We do not consider the electrical current which passes along different wires essentially different, because it may be used to write a message, light a jet, ring a bell, or cause the legs of a frog to twitch.

For reasons which need not be mentioned, it has been customary to reduce all possible classes of nerves to two, according to the direction in which they perform the service of conduction. Those nerves which conduct nerve-commotion outward from the nervous centres are called "efferent," or "centrifugal," or "motor." Those nerves which conduct nerve-commotion inward toward the nervous centres are called "afferent," or "centripetal," or "sensory."

Afferent and Efferent Nerves. — The attempt has further been made to reduce the two foregoing kinds of nerves to one class. It is properly claimed that a difference in direction does not *necessarily* prove an essential difference in function. In favor of such a difference, however, it has been urged that heat is a stimulus of afferent but not of efferent nerves; and that a constant current passing along an efferent nerve, so long as there are no sudden changes in its strength, does not make the attached muscle contract, while such a current does seem to excite impulses in a sensory nerve.

On the other hand, the rate of conduction in both kinds of nerves seems to be about the same; and, indeed, most of the laws, to which we are about to call attention, apply, essentially unchanged, to both. It may further be urged that even more marked differences than those referred to above can be accounted for by the differences in the sources of the stimulation. A molecular disturbance, which would be quite powerless to stir the sluggish muscle-fibres when transmitted to them by a motor-nerve, might occasion profound changes in the sensitive ganglion-cells of the central organ when transmitted to this organ by a sensory nerve.

Various attempts have been made, more or less successfully, to demonstrate by experiment that motor and sensory nerves can be made to discharge each other's functions. Some experimenters have succeeded in uniting the central end of the sensory nerve of the dog's tongue with the peripheral end of the motor nerve, on the same side. Others have reversed the course of the nerve-fibres in the tail of a rat, by bending this appendage over, and planting its end in the back. If these experiments are not quite satisfactory, those of Kühne may fairly be said to be conclusive. He showed that if we divide the broad end of the sartorius muscle of the frog into a forked shape, the same stimulation will ascend the fibrils of one tine of the divided muscle, and descend the fibrils of the other tine.

No good reason appears, then, why we should not consider all nerves as essentially alike in their powers of conduction. It is upon this assumption that the science of so-called "General Nerve-Physiology" is built up experimentally. In building up this science, the efferent nerves of frogs have been chiefly used for purposes of experiment. A preparation of such a nerve with a muscle attached is the subject whose behavior is investigated.

The Nerve-Muscle Preparation. — The most convenient form of machine for experiment in "general nerve-physiology" requires a freshly dissected (*gastrocnemius* or other) muscle of a frog with the attached (*sciatic* or other) nerve. Such a preparation can be kept alive for some time in a cool moist chamber. By the simple contrivance of connecting the end of the muscle with a lever, arming the lever with some means of making a mark (pen, bristle, or needle), and bringing its point to bear on a travelling surface (plain or smoked paper, or glass), the time and amount of the contractions of the muscle may be recorded. Stimulation may be accomplished with any kind of irritant, but for obvious reasons the electrical current is preferable as a rule. It may be applied under the greatest variety of conditions, and to any point in the nerve, and with any degree of intensity.

The line traced by the armed end of the lever, as it rises and falls with the contractions of the muscle, is called the "muscle-curve." This curve is a measure of the observable effect produced by irritating the nerve. If the electrical current flows with the course of the nerve toward the muscle, it is called "descending," or direct; if it flows in the opposite direction, it is "ascending," or inverse. The movement of the muscle which follows closing of the current is called the "making contraction," or "closing contraction"; that which follows its opening is called the "breaking contraction," or "opening contraction." When the single stimulations are repeated with sufficient rapidity, the spasms fuse into one prolonged effort of the muscle, known as "tetanus," or "tetanic contraction." The nerve may then be said, with the muscle, to be "tetanized."

CONDITIONS OF THE FUNCTIONS OF NERVES.

Of the conditions under which alone the nerves are capable of exercising their functions the most important are the following three: —

(1) **Vitality of the Nerves.** — A nerve cannot act as the conductor of a nerve-commotion unless it is *alive.* The process of conduction is not therefore merely mechanical, like that of electricity along a wire, but is physiological and vital. The death of the nerve is not, however, simultaneous with that of the body from which it is taken, or of the muscle to which it is attached. On the contrary, by careful treatment, it may be preserved alive for some time after excision. Since the nerve, unlike the muscle, has no death-rigor, it is difficult to say precisely when it is dead. The existence of electrical phenomena in the nerve for some time after it has ceased to excite the muscle is thought by some authorities to show its continued vitality.

Nerves, when dying, exhibit two marked changes of excitability. Immediately after being cut, the excitability of the nerve increases, and afterward sinks to zero by successive stages of diminution. The course of these changes is different for different portions of its length. Again, the lower portion of the cut nerve seems to preserve a given degree of vitality for the longest time. Hence "Valli's principle: *Nerves die from the centre to the periphery.*

Closely allied to the foregoing changes are those which take place when the cut nerve remains in its place in the living animal organization (*in situ*). For such a nerve the law of increased irritability immediately after section seems, in most cases, to hold good; the application can be tested, however, only in the case of motor nerves. Nerves, cut *in situ*, lose their vitality after a time—in warm-blooded animals, of three or four days, but in cold-blooded, of a week or more. A fatty or granular degeneration (discovered by Waller in 1850) takes place in nerve-fibres that are severed from the central organ; and this degeneration proceeds from the place of section to the extreme peripheral portion of the fibre. A cut nerve remaining *in situ* may be regenerated by the axis-cylinders growing out of the central portion and running into, and between, the sheaths of Schwann of the peripheral portion. According to some authorities the conductivity of the nerve is then regained earlier than its power of local irritability.

(2) **Use of Oxygen by the Nerves.**—As compared with the end-organs and the central organs, or even with the muscles, the nerves are relatively independent of the presence of oxygen for the exercise of their physiological function. The irritability of the nerves continues almost as long in a moist vacuum, or in indifferent gases, as in the air. It may be argued, however, from the marked dependence of nervous tissue, in general, upon a supply of arterial blood, as well as from the general mechanical theory of the nervous system, that some oxygen is an essential condition of the activity of the nerves.

(3) **Recovery from Exhaustion.**—The nerves, when "ex-

hausted" — as it is said — cannot perform their physiological functions. But exhaustion of the *nerves* is difficult to distinguish from exhaustion of the central organs or of the end-organs. In the case of the nerve-muscle machine Bernstein thinks he has shown that by far the greater part of the effects of prolonged and severe stimulation is due to the *muscle*-element in the machine; and that exhaustion in the nerve comes on much more slowly than in the muscle. Indeed, some have gone so far as to hold that the nerve is not exhausted at all, but resembles in this regard a metallic wire. But more recent researches seem to show — as indeed we should expect on grounds of general theory — that a prolonged tetanizing current may fatigue the nerve, even when the end-apparatus continues able to perform its functions. Ordinarily, however, when we are tired nervously, it is the central organs, or end-organs, rather than the conducting nerves, that are tired.

PHYSICAL PROPERTIES OF THE NERVES.

The phenomena called forth by irritating a nerve depend upon the character, amount, and method and place of application, of the stimuli employed. This dependence suggests certain truths as to the physical properties of the nerves as conductors.

Mechanical Properties of the Nerves. — The elasticity, ductility, cohesion, etc., of nerves are of little interest to the student of physiological psychology. More pertinent is the fact that all kinds of mechanical attacks upon the nerves excite them, and are followed by pain in case of the sensory nerves, and by contraction in the case of motor nerves. Tetanus may be produced with a toothed wheel or hammer. A certain suddenness of the shock seems necessary to excite the nerve. Pressure on a nerve may be gradually increased until its power of conductivity is lost, without exciting it. Slight pressure or traction seems to increase the irritability and speed in conduction of the nerve. Yet nerves may be cut so suddenly as not to excite them.

Thermic Properties of the Nerves. — Little is known as to the specific heat of nerves, or as to their power to conduct heat. But the effect of heat on the function of these organs is very marked. The results of experiment differ as to the degree of heat which will act as a stimulus upon the nerves. Considerable changes in the medium temperatures appear to have no effect. One investigator found that suddenly warming a nerve to about 35°–40° C. occasioned a spasm in the attached muscle; and warming to a higher degree produced tetanic convulsions. Long ago that noted authority, E. H. Weber, showed that heat and cold do not produce sensations when applied directly to the sensory nerve-trunks in man. For this peculiar sensory effect the intervention of end-organs seems necessary.

Four periods have recently[1] been distinguished in the effects produced by heat upon the irritability of the motor nerve. These are thus described: (*A*) Gradual increase to a maximum of irritability, — viz. 32.75°–39.25° C.; (*B*) then gradual diminution of irritability to its total loss; (*C*) condition of no irritability, a period coming at any point within 5° above the temperature of maximum contraction; and finally (*D*) development of heat-rigor.

Warmth increases the immediate expenditure of energy in an excised nerve, and so hastens its death; cold delays this expenditure and so conserves the nerve.

Chemical Properties of the Nerves. — The effect of most chemical agents on the nerve is to destroy without exciting it. Changes of the amount of water in the substance of the nerve affect its functional activity. A slight drying raises its irritability; and drying also produces contractions ending in tetanus. Swelling the nerve decreases its irritability to the point of entire loss. Certain acid and alkaline solutions also affect the nerve very much like drying it. Some organic substances, like urea, sugar, and glycerine, irritate the nerve. The principle seems to be, that *all chemical stimulation of the nerves is closely connected with the destruction of the nervous tissue.*

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[1] By Charles L. Edwards, in Johns Hopkins Studies from the Biological Laboratory, June, 1887.

Electrical Properties of the Nerves. — The resistance of living nerves to the electrical current is probably about the same as that of the muscles; it has been given at 50,000,000 times that of copper wire. The conductivity of the nerve has also been given as, on the average, 14.86 times that of distilled water.

The excitatory effect of the constant current upon the nerves follows the principle stated by that great explorer, du Bois-Reymond, in 1845. *This effect,* as measured by the contraction-curve of the muscle, *does not correspond to the absolute value of the intensity of the current* at each moment, *but to the change in this value* from moment to moment; and the effect is greater the less the time in which changes of the same magnitude in the current occur, or the greater their magnitude in the same length of time. The essential fact is that constant currents, while they remain constant, do not irritate the nerve; variations in these currents do irritate it.

Even upon the sensory nerves it is not certain that the constant current itself, apart from changes in its strength, can have much excitatory effect. The sensory experiences which follow such a current are chiefly due to changes induced in the end-organs and central organs.

Excitatory Effect of the Constant Current. — If we experiment with the electrical current upon a nerve we find that its excitatory effect is dependent upon the *direction* in which the current flows. The following table, by Pflüger, gives the results reached by a large number of observers: —

STRENGTH OF CURRENT.	ASCENDING CURRENT.		DESCENDING CURRENT.	
	Making.	Breaking.	Making.	Breaking.
Weak	Contraction	Rest	Contraction	Rest.
Medium. . .	Contraction	Contraction	Contraction	Contraction.
Strong. . . .	Rest	Contraction	Contraction	Rest or weak Contraction.

The most important point in this table is more clearly brought out by the following recent summary[1] of results: "Up to a certain strength of current a stimulus will give contraction when the cathode lies next to the muscle (*i.e.* the current is descending), which will give no contraction when the anode is in that position (current ascending). Above this strength the reverse holds, and a stimulus which is followed by contraction when the excitation has to pass the anode, evokes no response when it has to pass the cathode."

The excitatory effect of the electrical current upon the nerve is also dependent upon the *strength* of the current. It increases with the strength, from the lowest observable point, until it soon reaches a maximum; after this, further increase of the effect of the current is to be recognized only by the expanding of this condition of higher irritability — called "electrotonus" — over the extra-polar parts of the nerve.

The effect of the current upon the nerve also depends upon the *length* of nerve excited, and upon the *angle* at which the stimulus is applied. Up to a certain limit — fixed by different investigators at from $\frac{1}{12}$ to $\frac{1}{2}$ inch — the excitatory effect increases with the length of the nerve through which the current flows. The electrical current apparently does not excite the nerve at all when it flows through it precisely at right angles to the nerve's axis.

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[1] An Article by G. N. Stewart, in *Journal of Physiology*, Oct., 1889.

The *duration* of the current also influences its effect as a stimulus. It would appear that the current must act upon the nerve for at least about 0.001½ of a second in order to excite it. By cooling the nerve this "sluggish" period may be increased to nearly 0.02 of a second. In ordinary circumstances, however, it is thought that the action of the stimulus for 0.017–0.018 second will cause the muscles to contract as much as the same strength of current when constantly applied.

Electrotonus of the Nerves. — When the nerve of a nerve-muscle machine is under the influence of a constant current of electricity, very important changes in its condition are observed, as respects both its excitability and its conductivity. The general fact that such changes are produced as the effect of applying the constant current is undoubted. But the precise nature of some of these changes is disputed; while no theory has as yet been devised which will satisfactorily account for them all. We shall confine our account at present to the briefest possible statement of the more important alleged facts; any reference to theory which seems desirable at all, will be made in another connection.

The changed condition of a nerve, as respects its physiological function, which is produced in it by a constant electrical current, is called "Electrotonus." "Pflüger's law," so-called, states the case, in general, as follows: *The excitability of a nerve under the action of the constant current is increased in the catelectrotonized region* (that is, on both sides of the cathode, or negative electrode, — the point where the current leaves the nerve), *and diminished in the anelectrotonized region* (that is, on both sides of the anode, or positive electrode, — the point where the current enters the nerve). This law is said, by a chief modern authority, to hold good of all kinds of stimulus, and in all cases.

The electrotonic effect of the constant current upon the nerve, like its direct excitatory effect, is influenced by the strength of the current, by its direction, its making and breaking, and by the length of the nerve through which the current flows. The changes called "electrotonic" occur in the region of the negative pole (cathode) immediately upon making the current; they then quickly but slightly increase and afterwards fall off more slowly again. In the region of the positive pole (anode) the changed condition develops more slowly until it reaches a maximum, and then gradually diminishes.

Recent researches have led some investigators to hold that the *conductivity* of the nerve is changed by the constant current in a different manner from its *excitability*. In its electrotonic condition — that is to say — the conductivity of the nerve is found to be less around the cathode than around the anode. From this the conclusion is drawn that the origin of the process of excitation of the nerve is not like its propagation. Into the refinements of this change, when the stimulus of the electrical current is applied to different parts of the nerve outside, or within, the poles (inter-polar and extra-polar) we cannot enter.

PROCESSES EVOKED IN CONNECTION WITH THE FUNCTION OF NERVES.

When the nerve is excited certain processes connected with its physiological action are indicated, in a more or less obvious way.

Mechanical Processes in Excited Nerves. — No appreciable mechanical changes, like the contraction of the muscle-fibre, can be detected in excited nerves. Whatever changes occur are invisible and impalpable. In the nerve-cells, however, mechanical changes can be detected as the result of excitation. Repeated and prolonged excitation of the ganglion-cells of the posterior root results in shrinkage of their nucleus and of the cell-protoplasm; and in changing the nucleus from a smooth and regular to a jagged and irregular outline. The large cells show most of this effect of being obliged *to do work;* the small cells little or none at all. The average shrinkage of the large cells is found to be measurable as — in some cases — from 24 to 36 per cent.[1]

Thermic Processes in Excited Nerves. — If any rise of temperature is produced in a nerve by irritating it, the amount is exceedingly small. Helmholtz concluded that his means of detecting heat to within a few thousandths of a degree showed no such change in excited nerves. On the other hand, nervous excitation appears to produce a perceptible change of temperature in the centres of the brain; and this change can scarcely be due wholly to increased flow of arterial blood. But to this subject we shall return in another connection.

Chemical Processes in Excited Nerves. — The most obvious indications that chemical processes are concerned in the physiological functions of excited nerves are certain changes in "reaction," or in taking stains, which some observers claim to have found. It has been asserted that, after extreme exertion caused by cramping in cases of strychnine-poisoning, the nerves have an acid reaction. Very recently two observers, on comparing two frogs, one of which was killed after resting and the other after having the eighth nerve stimulated for an hour, found several per cent. more nuclei staining red in the stimulated than in the rested pair of nerves. Evidences of marked chemical changes in the nervous centres, due to work done there, are of course not wanting. But the direct experimental evidence for the same thing in the nerves is still incomplete.

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[1] See the *American Journal of Psychology*, May, 1888, pp. 479 ff.

Electrical Processes in Excited Nerves. — In 1843 du Bois-Reymond found what he considered direct experimental proof of the existence of electrical currents in the nerves. It had, of course, been previously conjectured that nerve-commotion is a phase of electricity. But this experimenter discovered that, if we cut a nerve and then apply an electrometer to it, the cross-section is negative toward the longitudinal surface of the nerve. The current, which is thus shown to be flowing in the nerve, from the cut end to the equator, is called "natural nerve-current," or "current of rest." Its electro-motive force is greater, the larger and thicker the nerve. In the sciatic nerve of a frog it is given at from 0.022 to 0.046 of a Daniell's cell. It continues for some time after the irritability of the nerve is lost.

The same investigator found that the "current of rest" is diminished in energy by tetanizing the nerve. This swing of the needle which measures the "current of rest," backward toward zero when the nerve is repeatedly irritated by passing through it an interrupted current, is called "negative variation." It shows that the electro-motive force of the nerve is diminished by the nerve being excited.

The bearing of these phenomena also upon a general mechanical theory of the nervous system will be referred to in other connections.

LAWS OF CONDUCTION IN THE NERVES.

Only a very few statements can be made, with respect to the physiological function of the nerves as conductors, which are properly entitled to the dignity of being called "laws." And these laws are determined almost wholly by experiments with the motor nerves of frogs. There is evidence, however, in respect to certain of the more simple forms of activity, that all nerves conduct nerve-commotions in essentially the same way.

Relations of Magnitude between Stimulus and Result. — On attempting accurately to compare the amount of the stimulus applied to the nerves with the amount of resulting nervous impulse, great difficulties are encountered. There is indeed no absolute measure for either of the values which it is desired to compare. Electricity is the only stimulus of the nerves that admits of a fairly approximate measurement by objective standards. The effect produced by stimulation is almost wholly manifested in organs with which the nerve is connected, rather than in the nerve itself. It does not, therefore, admit of easy direct measurement.

Measuring the result of the stimulus in the nerve by the amount of contraction produced in the connected muscle, we find it to be (as has already been indicated, see p. 126) within certain limits, directly proportional to the amount of the stimulus. Two remarkable apparent exceptions to this law are noted: (1) On increasing the amount of the stimulus beyond the point necessary to produce the first maximum contraction, another stage is reached in which the effect further increases, in proportion to the stimulus, until a second maximum is gained. (2) In some circumstances, after reaching the first maximum, the effect diminishes with the increase of the stimulus, then rises on further increase until the second maximum is reached.

The excitability of the different nerves is different, and of different localities of the same nerve under different circumstances. It is usually greater in winter than in summer. In the cut nerve it is greater near the cross-section. The reflex effects of stimulating a sensory nerve are said to be greater the nearer the central organ the stimulus is applied. The lower part of a nerve is found more excitable under the ascending, the upper under the descending, induction-current.

Summation of Stimulations in the Nerves. — In order to keep the successive waves of nerve-commotion apart, an interval of about $\frac{1}{100}$ second must elapse between the repeated stimulations. Otherwise they fuse, and tetanus results. If this interval is observed, the combined effects of the different stimulations may be piled, or "summed" up, in the nerve. They may then be seen in superimposed contractions of the muscle. This law is also important for a mechanical theory of the nervous system.

Speed of Nervous Impulses. — In 1844 the great physiologist Müller declared it forever impossible to know the speed of the nervous impulses. In 1850 Helmholtz announced the speed as from 26.4 meters (86.6 feet) to 27.25 meters in motor nerves. Subsequent researches have, in the main, confirmed the conclusion of Helmholtz. The rate of nervous impulses varies greatly, however, under different circumstances. By changes in temperature results can be obtained in the motor nerves of man, varying from 98 feet to 295 feet per second. The general conclusions for the sensory nerves favor numbers lying between 98 and 131 feet per second. As soon as the strength of the stimulus rises above a certain limit, the speed of the resulting impulses appears to increase with the strength of the stimulus.

In the spinal cord and in the brain the speed of the nervous impulses is, in general, much slower than in the peripheral nerves. This is due to the far greater complexity of these organs, and to the accompanying possibility of the impulses spreading into side tracts, as it were: in brief, the greater variety and amount of the work that must be done. Exner calculated the speed of motor impulses in the cord at 11 to 15 meters (about 36 to 49 feet). The sensory impulses of the cord, he thought, travel at the average rate of about 8 meters (about 26¼ feet). Sensations of touch arise, as we all know by experience, earlier than sensations of pain, when we are struck with a missile, or burned with a brand. Some have maintained, therefore, that the speed of the former is to that of the latter as from 27 to 50 meters compared with 8 to 14. The argument is not conclusive, however, since we do not know the length of the paths by which the impulses that produce the two kinds of feeling travel, or the kind and amount of cerebral action which they respectively involve.

Integrity of the Nerves Necessary. — The slightest separation of the parts of a nerve, even if its cut ends are left in the closest mechanical contact, destroys its power to conduct nervous impulses. Nerve-commotion, unlike the electrical current, cannot jump the smallest gap in the nervous structure. The ancients knew that tying a nerve prevents its action. They explained the fact by saying that the flow of nervous fluid was thus hindered. So also does the fineness of the localization which belongs to the organs of motion, and especially to the organs of special senses, like the skin and eye, indicate the physiological isolation of the nerve-fibre during its course between the end-organs and the central organs. It would further seem that the law of the "specific energy" of each nervous element is connected with the assumption necessary to explain the phenomena attendant upon the starting and propagating of nervous impulses in the conducting nerves. But to this subject of the "specific energy" of the nervous elements we shall recur at another time.

When speaking of *conduction* in the nervous substance of the spinal cord or of the brain, we are not to think of the nerve-commotion as moving along one fixed path, after the exact analogy of the far simpler case of the nerve-muscle machine. The spinal cord does not act as a "perfectly isomorphic medium" for the transmission of nervous impulses. Its extremely complex structure has shown us that it is not adapted to act as such a medium. The case of the brain in this regard is even more complicated. After all the thousands of experiments which have been performed in what is called "nerve-physiology," we are not yet in a position even to indicate with scientific exactness a complete mechanical theory of those molecular wave-like disturbances which the application of stimuli produces in a single nerve attached to a muscle. How much less then do we know of the molecular science of the nerve-commotions in the cord and in the brain? Yet that the nerve-commotions are molecular wave-like changes there can be no doubt. And these changes are connected with, but are not identical with, those mechanical, thermic, chemical, and above all, electrical processes, which have just been described.

CHAPTER VI.

REFLEX AND AUTOMATIC NERVOUS FUNCTIONS.

WHEN a physiological function is occasioned in some peripheral nerve, independently of a so-called act of will, by the stimulation of some other peripheral nerve, this function is said to be "reflex." In other words, reflex action is the result of the secondary stimulation of one nerve, through a central organ, by the primary stimulation of some other nerve. On the other hand, all excitations of the nervous system which originate in the nervous centres themselves are called "automatic." Doubtless this term must often be used to conceal our ignorance of the real origin of a neural process; doubtless also, many processes, which at first sight appear to be automatic, are afterwards discovered to originate reflexly. Notwithstanding this, nervous impulses which result in the movements of the muscles, or in the inhibition of such movements, apparently originate in the central organs under the action of internal stimuli. But such automatic activities belong distinctively to the central ganglia of the brain.

Kinds of Reflex Action. — Theoretically, various kinds of reflex nervous action are supposable in the nervous system. Thus two motor nerves might be combined through a central organ ("co-motor reflexes"); or an excitation arising in a motor nerve might, without an act of will, be transferred to one or more sensory paths ("reflex-sensory"). As to the existence of "co-sensory reflexes" — or cases where the excitation of one peripheral sensory nerve, through the central organ, occasions the excitation of another locally different, peripheral, and sensory nerve — there can be little doubt. The nose, for example, may be made to tickle by looking at the sun; and strong rubbing or squeezing of one muscle may sometimes occasion pain in muscles located far away on the surface of the body. But only one kind of reflex functions of the nervous system seems hitherto to have been made available for purposes of scientific experiment. These are the so-called "reflex-motor," or "sensory-motor." Such terms are given to reflex action when a motor nerve is stimulated in a secondary way, through a central organ, by applying stimulus to sensory nerve-endings.

We must carefully guard ourselves, however, from the misconception that lurks in the word "reflex." The effect of the central organ is never that of simply turning back, or *reflecting*, a nerve-commotion from one path to another. On the contrary, the passage of a nerve-commotion through a central organ profoundly modifies both the condition of the organ and the character and distribution of the nerve-commotion itself.

THE SPINAL CORD AS A CENTRE OF REFLEX MOTOR ACTIVITIES.

Our previous survey of the structure of the spinal cord suggests the truth that it is specially adapted to act as a central organ in the exercise of a variety of reflex-motor functions. The older investigators assumed a great variety of special mechanisms, consisting of distinct systems of sensory and motor nerve-fibres, with connecting cells, appropriated for the sole purpose of executing the various kinds of reflexes. Modern investigation tends rather toward the view that there are no special elements of the cord appropriated *merely* to reflex-motor functions. The whole structure of the organ is such as to adapt it in all its parts, for this as well as for other nervous activities.

The Reflex-Motor Machine. — The most convenient piece of mechanism for experimenting to discover the laws of spinal reflexes is the so-called "brainless frog." This preparation consists of the spinal cord, still alive, but separated from the brain by section below the medulla oblongata. If the flank of such a frog be touched, a slight twitching of the muscles, which lie immediately below the spot of the skin thus stimulated, will result as a reflex motion. If a hind leg be stretched out and pinched it will respond in a purposeful way to withdraw itself from the irritation. Increasing the strength of the stimulus will elicit reflex motions involving the fore leg of the same side; then both legs of the other side; and perhaps, finally, all the muscles of the body. If when one leg of a brainless frog is irritated it is at the same time prevented from movement, the cord of the preparation will sometimes use the other leg to accomplish the purpose of removing the irritation.

Phenomena, similar to those obtained from the brainless frog, may be obtained from other brainless animals. A decapitated salamander, when the skin of one of its sides is pinched, will bend that side into a concave shape.

It was for some time supposed impossible to obtain similar phenomena from the spinal cord of mammals. And, indeed, the spinal reflexes in the case of a mammal whose cord has been disconnected from his brain, are, immediately after section, comparatively weak and purposeless. But if such an animal be kept alive for some time, then strong, varied, and purposeful movements will follow sensory stimulation of the skin of the parts below the place of section. After some weeks or months, reactions resembling those described in the case of the frog begin to appear. Moreover — a very significant fact! — it is found that the breed, sex, age, and training of the animal determine the character of these reflex brainless movements.

Strength and Suddenness of Spinal Reflexes. — Continuous irritation of the skin of a brainless animal, if *slowly increased*, does not give rise to reflex movements. But a much smaller degree of stimulus, if suddenly applied, will call forth such movements. Repetition of the shocks with the electrical current is much more effective than is the constant current, in starting spinal reflexes. And here we are reminded again of the law already announced, as holding good in "general nerve-physiology" (see p. 125). A decapitated frog may be placed in water, and the water slowly heated until its life is destroyed, without its showing any reflex activity. Even normal frogs — though with much more difficulty — can be heated, either locally, with one leg in the water, or all over, while sitting on a cork in a cylinder of water, without causing motion, if the increase of temperature be gradual enough.

Speed of Spinal Reflexes. — It has already been said (p. 132) that the process of conduction suffers a delay while passing along the spinal cord. The time of "cross-conduction" in the cord also seems to depend upon the strength of the stimulus. By increasing its strength — it has been calculated — the time consumed by the specifically central processes may be diminished from 0.055 to 0.047 of a second. With very strong stimulus the time occupied by the central processes becomes almost too brief to detect.

Condition of the Spinal Cord. — The character of the resulting reflex movement is very largely determined by the condition of the cord when the sensory impulses enter it. Lesion increases the excitability of the part below the lesion. Some drugs heighten and some depress its excitability. When the cord is poisoned with strychnine, for example, the slightest stimulation will cause such an explosion in it, and such a diffusion of energy along unaccustomed paths, that convulsive cramping is occasioned over the entire body. Changes of temperature also seem to affect the reflex-motor activities called forth by stimulating the spinal cord.

Effect of Locality. — The extent and character of the spinal reflexes depend, in a remarkable way, upon the locality to which the stimulus is applied. The most remarkable difference is perhaps that evoked by irritating some spot on the skin of the brainless animal, and then comparing the result with that obtained by applying the stimulus directly to the trunk of the sensory nerve. A slight irritation of the skin may result in the extended movement of many muscles, combined in a purposeful way. The direct stimulation of the trunk calls forth irregular movements in a few muscles only. *What* particular reflex actions follow stimulation, depends upon the particular locality of the skin to which the stimulus is applied.

Laws of Spinal Reflexes. — The most general rule of the reflex-motor activities of the spinal cord may be stated in terms like the following: The irritation of a sensory nerve with a small degree of stimulus gives rise to reflex movements which originate in the cord on the same side, at about the same altitude as that at which the sensory impulses enter the cord; increased stimulus gives rise, also, to movements that arise on the other side of the cord, at about the same altitude; a still greater increase, to those that originate on both sides of the cord, with the preference, however, to the same side.

It would seem, then, that the nerve-commotion which enters the cord is dispersed, first, along the network of cells and fibres near the point of entrance on the same side; then, across, at the same altitude, to the other side; then, up and down on both sides of the cord. Excitation, started anywhere in the cord, tends to radiate in all directions, but with the preference for certain paths marked out by the structure and habits of the cord. Hence the spinal cord has been called "the organ for the dispersion of irritation."

Alleged Automatic Functions of the Spinal Cord. — This organ is not capable of "irregular automatism," — that is, of such spontaneous excitation as takes place in the higher centres of the brain, on volition. It does, however, discharge certain functions that are less certainly reflex than those which have already been considered. What is called the "tonic action" of the cord upon the muscles is a marked instance of such functions. The fact that this action does not simultaneously contract all the muscles connected with the cord, or any one set of them with the same energy as any other, throws some suspicion on its automatic character. Moreover, we can often ascribe the "tone" of the muscles of the brainless animal to the action of subtle influences, such as movements of the air, etc., upon the surface of the skin. If a brainless frog be hung up, after having the sciatic plexus cut on one side, the muscles of the leg on the other side have the better "tone." But the same flaccid condition of the muscles on the cut side exists when only the sensory roots of this plexus are cut.

The circulation of the blood in a brainless animal seems to be in a measure dependent upon the condition of the spinal cord. Hence it is claimed that so-called "vaso-motor centres" exist in the cord. Circulation may continue with regularity in a decapitated frog; but the removal of any considerable part of the cord affects it. This result appears to arise through the loss of tone thus occasioned in the blood-vessels; and the mechanisms for expanding and contracting these vessels are apparently interlaced with those for contracting the skeletal muscles, in all parts of the cord. Hence the possibility that part, at least, of the result may be reflex rather than automatic.

Centres in the Spinal Cord. — The mechanism of this central organ is so constituted as to connect the motor with the sensory tracts, *more favorably in some regions than others*. Such regions are called "reflex centres" of the spinal cord. A considerable and indefinite number of such centres exist; and some of them have been located. It has, indeed, been laid down as a general principle that "the spinal cord is the proximate centre, the proximate physiological *hearth of excitation*, for all the nerves that originate from it." Since the very influential experiments of the German investigator, Goltz, upon the spinal cord of dogs, many functions formerly ascribed to the brain have been shown to have their proximate centres in the cord.

The spinal reflex centres of different animals differ according to their structure and habits. With frogs, stimulation of any portion of the skin induces reflex movements in all of the muscles. With rabbits, however, a reflex action of a hind leg can be caused by sensory stimulation of a fore leg, *only in case* one-third or more of the medulla oblongata is left attached to the cord. "Trotting reflexes" — that is, movements of the diagonal opposite extremities by stimulation of one limb — can be obtained only in animals with which such movement is natural. According to the researches of Ferrier and Yeo, the stimulation of each motor root of the nerve-plexuses of monkeys calls forth combined movements involving the co-operation of numerous muscles widely separated anatomically. But all the resulting movements are such as are seen associated together in the ordinary activity of the animal.

The spinal cord of every animal seems, then, to be an embodiment of the specific functions and of the habits of the species to which the animal belongs; as well as of the individual peculiarities acquired by the animal in the previous use of the cord.

Nothing more than a reference is necessary to the various centres which experiment discovers in the spinal cord, — such as the vaso-motor, those for micturition, defecation, parturition, etc.

Excitability of the Cord as a Whole. — The question has been much debated whether the spinal cord as a whole is excitable or not. Some have held that the movements obtained by applying a strong stimulus directly to the cord arise only reflexly, — in so far, that is, as the stimulus involves the sensory roots. The cord, therefore, is held to contain no motor elements that are directly excitable except the central paths of the nerve-roots. Others have held that, while the gray matter is absolutely inexcitable and the posterior columns very excitable, the anterior columns possess only a moderate degree of excitability. The evidence is therefore conflicting. It is scarcely possible to be more precise than to affirm that certain longitudinal parts of the cord are susceptible to direct irritation, — without saying what, exclusively, these parts are.

Inhibitory Effect of the Brain. — If the legs of a frog are allowed to dip into dilute acid, the interval between contact with the acid and the withdrawal of the cord is considerably lengthened when the spinal cord remains undivided below the medulla oblongata. The cord alone withdraws the leg quicker than the cord as influenced by the brain. Moreover, the cord *alone* can be depended upon to respond with great regularity, in the form of definite reflex movements, to a given amount of irritation applied to a particular spot. But connection with the brain disturbs this regularity. The cord is thus said to be *inhibited* by the brain. We cannot, accordingly, so well calculate what the cord, when under the influence of the brain, will do.

We do not enter upon the disputed question whether a special inhibitory apparatus belongs to the brain in its connection with the spinal cord. There are no sufficient grounds for assuming the existence of such a mechanism; but then, as Dr. Ferrier has said: "The nature of the inhibitory mechanism is exceedingly obscure." The important thing to notice, however, is that *the cord, while having a certain independent power of functioning in various ways, is controlled by the higher centres of the brain.* Were this not so, we could not, on the one hand, commit to it the task of doing reflexly so many things *for us;* and, on the other hand, *make it* carry out our desires by acting, or refraining from acting, according to our will. In standing, walking, running, playing upon musical instruments, writing, using tools, etc., the activities requisite are exceedingly complex. They involve a complicated and rapid interchange of the following three processes: (1) spinal reflexes; (2) reflex-motor impulses that imply the trained inhibitory and controlling action of the centres of the brain in connection with the special organs of sense; and (3) special and more definite motor innervations that are due to conscious acts of volition. For all the life of habit in its control over the movements of the trunk and limbs, and for the possible inhibition, breaking, or changing of such habit, the functions of the cord in their relations to the functions of the higher parts of the cerebro-spinal axis, are indispensable.

REFLEX AND AUTOMATIC FUNCTIONS OF THE LOWER BRAIN-CENTRES.

On passing from the spinal cord into the brain, the difficulty of determining the special functions of the different nervous centres becomes greatly increased. The phenomena become much more complicated; and the parts are less easily reached for purposes of observation and experiment.

Methods of Observation and Argument. — The methods of research into the functions of the central organs of the brain are chiefly these two, — stimulation and extirpation. Both, of course, can be in general applied only to the lower animals. In the first method, some form of stimulus is used to irritate a definite locality in the brain, and the results of such irritation are carefully noted. To use this method the organs must be exposed. With the skill and safeguards of modern surgery this can be done for a considerable portion of the brain, without permanent injury to other organs or death of the animal. Those organs that lie deepest cannot be treated by this method with the same success. The stimulus of the electrical current is by far the most convenient for experiment; but care must be taken to circumscribe the effects of its diffusion through the surrounding substance.

With the method of extirpation, the difficulties and the need of caution are even greater. The "secondary" effects of the lesion of any part of the brain of an animal are oftentimes greater than those which can be justly ascribed to the injury of the organ primarily affected. On the whole, then, it is very difficult to arrive at a consistent view of the facts. The phenomena observed are often confusing and even apparently self-contradictory.

The argument from such data of facts can scarcely be expected to yield a perfect demonstration. Valid objections may be raised to the very nature of the inferences made by many observers. It is a doubtful assumption, for example, that the activities which remain, when some of the organs of the brain of an animal are extirpated, belong wholly to the organs that remain, while the activities that have disappeared belong wholly to the organs that have disappeared. In such an exceedingly complicated mechanism as the brain, with its extremely complex and close interrelation of parts, the distinct marking off of "organs," and "areas," and "centres," does not command our perfect confidence. Specific differences belonging to different kinds of animals, and individual differences between the different members of the same species (in the case of the higher animals), must certainly be much more taken into account than they have heretofore been. It is difficult to credit the inference that a particular portion or area of the brain's substance is *the* (only) organ for particular functions, so long as instances may be brought forward where the function has been discharged in the absence, or after the destruction, of such alleged "organ."

The difficulties of investigation of this subject are greatest in the case of man. For man, of all the animals, has the most complicated brain, and the most complex system of functions connected with this organ. Moreover, he is of all animals apparently — in his developed and adult life — least dependent for his higher psychical activities upon the condition of any small circumscribed portions of the brain. Nor can he be *experimented with* as can the lower animals. Inferences from them to him need to be guarded with special care, so much does he differ from them both in brain and in mind. The testimony of pathology is, generally, far from satisfactory. For when disease destroys the substance of his brain, it does not nicely limit or definitely announce the stage and spreading of the lesion it produces.

In spite of all difficulties, however, the localization of reflex and automatic functions in the brain of the higher animals, including man, has made great progress within the last twenty years. Indeed, it is within this time that the *science* of "cerebral localization" may be said to have been established. It is even at present worth, for man, far more than it has cost, whether of scientific painstaking on his part, or of pain-bearing on the part of the lower animals. It promises for the future a great extension of our knowledge of the relations of man's body to his mind; and — what is even more important — the ameliorating or cure of some of the most distressing of human ailments.

PARTICULAR FUNCTIONS OF THE MEDULLA OBLONGATA.

Above the spinal cord the medulla is the organ about whose functions we have the most precise information. In general it may be said to be the organ of the "vegetative" and also of the lowest animal life.

Reflex-Motor Functions of the Medulla. — These are more intricate and of a higher order than those belonging primarily to the spinal cord. They are particularly such as stand related to the vital functions of the heart and blood-vessels; to respiration and its allied movements in coughing, sneezing, etc.; to muscular movement in swallowing, vomiting, etc.; and to the mimetic movements of laughing and weeping. Some of these functions are purely reflex, some only partially so. Thus one cannot swallow except through action of the medulla; but the lungs and heart continue to move after the paths between them and this organ are destroyed. Sensory stimulation of the medulla may occasion reflex movements along a large number of motor tracts. Thus irritation of the throat will occasion simultaneously, swallowing, coughing, shedding tears, contortion of the countenance, and changes of respiration and heart-movement.

Automatic Functions of the Medulla. — The chief automatic centres of this organ are those connected with breathing, the movements of the heart, and the innervation of the blood-vessels. The excitation in these cases must be supposed to originate as a neural process within the organ; and the stimulus causing it is doubtless to be found in the changing blood-supply. The medulla seems peculiarly susceptible to the condition of the blood. It is probably due to the periodic reoxidation of the blood by the rhythmic action of the lungs that the medulla sends out rhythmic impulses from its respiratory centre to the lungs.

Centres in the Medulla. — This small piece of nervous matter may be said to be packed full of important vital centres. Among these the *respiratory centre* was first located by the French physiologist Flourens in the V-shaped apex of the fourth ventricle, or beak of the *Calamus scriptorius*. Since the smallest injury here causes complete cessation of respiration, he called it the "vital knot" (*nœud vital*). Later investigators have located this centre somewhat higher up. With it the various modifications of respiration — such as sighing, sobbing, yawning, crying, laughing, coughing, sneezing, hiccoughing — are connected.

A *vaso-motor* centre exists near the middle part of the medulla. It is probably both automatic and reflex. The removal of the parts in front of the medulla causes no perceptible influence on the blood-pressure; we therefore conclude that this organ itself contains the principal vaso-motor centres of the brain. Through it very complex muscular movements connected with changes in the circulation can be called forth, as witness the effect of a draught of air. In the same organ is a so-called *cardio-inhibitory* centre; it is through this centre, probably, that the heart is stopped by impulses originating in the brain, when severe pain or sudden and great emotion overpowers us.

The *centre of deglutition* lies still higher up. Destruction of this organ makes swallowing impossible. Centres connected with the secretion of spittle, sweat, tears, etc., have been located in the same region, — namely, the floor of the fourth ventricle. But we need not enter upon further details in this matter.

Co-ordination of Movements by the Medulla. — If this central organ be left connected with the spinal cord, but severed from the organs lying above it, the frog thus prepared becomes a more complex mechanism than is a simple spinal cord. Such a preparation will execute movements which the cord alone cannot execute. It will not, indeed, move spontaneously; but when irritated, by being placed in unnatural or uncomfortable positions, it will behave in a highly purposeful way. Laid on its back it will make efforts — generally unsuccessful — to turn over. Placed in the water it will swim, — with movements less perfect than those of the normal frog, but much more complex than those possible for the cord alone.

The medulla oblongata of mammals seems capable of executing very varied purposeful co-ordinated movements of the muscles. A young rat, with its higher central organs severed from the medulla, will cry when its toes are pinched, will swallow, and perform complex movements of the limbs. Infants, born with the centres above this organ undeveloped, perform the associated movements of sucking when put to the breast. Moreover, injury to this organ seems to have a marked effect on the co-ordination of the muscles. The most recent investigations connect the upper part of the medulla with the gray matter of the third ventricle, and with the semi-circular canals, in balancing the animal and otherwise co-ordinating its muscular movements, in response to impressions of touch.

Associations among the Centres of the Medulla. — The different small areas of this organ are very curiously related in regard to their physiological functions. Some of them are more excitable than others. Some of them can be voluntarily excited; but others cannot. Some of them are regularly associated together in their functions; some, seldom; some, never. We can voluntarily control the movements of the lungs, within certain limits; but cannot stop, or quicken, by a volition, the movements of the heart. We can at will make the medulla execute a cough, but not a sneeze. We can call the swallowing centre into operation without involving any other centres. In general, the things which the medulla does *for us*, without taking account of the condition of consciousness, are much more important than the things we can *make it* do, by volitional impulses sent from the cerebral hemispheres.

BEHAVIOR OF THE ANIMAL DEPRIVED OF ITS CEREBRAL HEMISPHERES.

An animal which possesses all the nervous substance of the brain except the cerebral hemispheres, is capable of executing movements that differ greatly from those already described as belonging to the spinal cord and the medulla oblongata. Few of these movements, indeed, appear perfectly spontaneous or highly intelligent. And such movements as have this appearance may generally be explained as resulting from the complicated mechanical interaction of the parts remaining, — cord, medulla, pons, crura cerebri, cerebellum, corpora quadrigemina (or optic lobes), and basal ganglia, — in response to a variety of connected sensory impulses to which the parts are peculiarly susceptible.

The two animals, by experiment upon which most data for forming a conclusion respecting these organs are derived, are the frog and the pigeon. They are certainly far enough removed from man in their nervous structure and mental life. But of late, considerable success has been obtained in keeping alive the higher mammals after loss of large portions of their cerebral hemispheres. By supplementing such observations with those of human pathological cases, and by arguing upon general grounds of comparative anatomy and physiology, a tolerably clear view may be obtained of the most general uses of all those parts of the brain that lie between the medulla and the cerebral hemispheres.

A frog from which the cerebral lobes alone have been removed will, when appropriately stimulated, move about almost as perfectly as a normal frog. It can swim well, can leap and crawl. It can turn over easily when laid on its back, and can balance itself on a tilting board. Submerge it in water, and it will rise to the surface for air.

It will avoid objects by guidance of the light. On the other hand, it seems stupid, pays no attention to flies placed near it, and will remain motionless, if kept from irritation, for hours.

The case of the pigeon from which the cerebral hemispheres have been removed has been frequently investigated. Certain details respecting its behavior have, however, never been satisfactorily settled. The most recent careful and extended observations describe the phenomena about as follows: For a few days after losing their hemispheres pigeons execute no spontaneous movements. Soon, however, the time spent by them in a slumberous condition becomes shorter, and they begin to wander around the room without weariness. Their movements are guided by sight from the first. Toward the end of the first week they will clamber over a wall 12 centimeters high; a few days later they will mount in the corners of an enclosure 17 centimeters high. Their movements seem perfectly regulated by impressions of touch. They balance themselves on the hand or the edge of the table. But noises do not appear greatly to influence their movements.

But do the actions of pigeons thus deprived of their cerebral hemispheres show *spontaneity* and *striving* for a goal? This question is difficult to answer in a perfectly conclusive way. Such birds will move around by day in a very lively fashion, and sleep fast at night. Many of their movements seem to have their origin in vegetative functions; but some of them also in complex impressions of the special senses. When dislodged from the hand, or from a stick, by turning it, they will aim their flight toward a definite object; they exhibit a preference for one object rather than others, as a place for alighting. They do not appreciate the color or smell of food, and will eat it when soaked in salty and other infusions; but even normal pigeons have scarcely any higher perception of the difference between grain and stones than that which is based on difference in size and weight. They do not feed themselves, — even when the grain is put into the front part of their bills. It is doubtful whether this is due wholly to lack of perceptive power or also to a lack of power for making the necessary co-ordinations.

On the whole the conclusion seems warranted that the bird which has lost only its cerebral hemispheres moves in a world of bodies whose situation, magnitude, and form determine its movements, but whose apperceived relations to the bird have ceased to influence it. It literally "*minds*" nothing. It exhibits no fear of particular objects; no recognition and no preference — of a sexual or other kind.

The phenomena which occur in the case of the higher mammals, on partial or total loss of the cerebral hemispheres, tend to confirm the same conclusion. The maimed rabbit or rat will co-ordinate its muscular movements in response to sensory impulses from the organs of touch, hearing, and sight. But the definitely psychical qualities seem largely or wholly to have departed from the actions of the animal. The case of the more intelligent of these mammals will be further considered in a subsequent chapter.

The organs of the brain which lie between the medulla oblongata and the cerebral hemispheres are all very intimately related in their functions. To a certain extent they act independently; within certain limits they can assume each other's functions. They have largely the same connections with the peripheral organs of sense and motion. In general, they may be said to constitute that portion of the nervous mechanism which serves as the central organ for the complex co-ordination of impulses of the special senses with the control of the motor apparatus. They mediate a large part of that incessant and complicated readjustment of the animal's body which responds to the effect of the environment on the peripheral organs of sense. We do not in this connection consider to what extent their function necessitates or involves "sensations," in the only correct, *psychical* meaning of the word.

PARTICULAR FUNCTIONS OF THE CEREBELLUM AND BASAL GANGLIA.

It is very difficult to assign the particular place which belongs to each of the organs that lie between the medulla oblongata and the cerebral hemispheres, under their general function as already stated.

Functions of the Cerebellum. — Testimony as to the effect of the extirpation or lesion of the cerebellum of mammals is very conflicting. Almost the entire length and breadth of its surface, both gray and white matter, may be removed with little or no observable result. On approaching the strands connected with the middle peduncles, disturbances of motion begin and increase rapidly in proportion to the amount of substance removed. Many of these disturbances, however, are only temporary; permanent disturbances occur, as a rule, only when the injuries affect the lower third of the organ.

One-sided lesions of the cerebellum seem to have a much greater effect upon the co-ordination of motion than that obtained from symmetrical lesions. The former — especially when sudden — occasion, at least temporarily, peculiar rolling movements of the eyes, suggestive of vertigo. The entire body of the animal also rolls around its own axis, — generally, though not invariably, toward the injured side. In all cases of lesion, the places of the union of the cerebellum with the medulla and with the crura cerebri seem most important.

The evidence of pathology respecting the functions of the cerebellum is, in the case of man, even more conflicting than the evidence of experiment with the lower animals. Several well-known instances have occurred where the cerebellum was either entirely wanting or had become almost totally destroyed by disease. In most, if not all of these instances, the balancing power of the patient was imperfect. Some investigators have regarded cerebellar ataxy as an almost unfailing result of the disease of the *vermis* of this organ; but others have pointed out numerous cases where this result did not follow, even when the disease involved the entire *vermis*. During twenty-four years ending 1887, Dr. Allen Starr found 160 cases of cerebellar disease reported in American medical literature, in 40 of which symptoms and autopsies were somewhat carefully described. Of these 40 cases there was —headache in 26; insubordination of the limbs in 25; vertigo in 20; vomiting in 18; blindness in 14. The same year a German authority reported that, of 364 cases of cerebellar disease, 260, or 71 per cent., had headache; 49 per cent., nausea; 33 per cent., affections of the eyesight.

It must be admitted that the entire evidence makes it difficult to place much confidence in any induction respecting the particular functions of the cerebellum in man. But on the whole, it indicates that this organ is concerned in securing *precision of adjustment* and *balance* of the two sides of the body, in response to impressions of sense (especially perhaps of sight and touch in the most general meaning of the latter word). In discharging this office, the cerebellum seems to be connected with the semicircular canals.

It need scarcely be added that modern physiology gives no support whatever to the hypothesis of Gall, who connected sexual feeling with the cerebellum. Nor is there any good evidence to show that it is the particular organ of any emotion, instinct, or form of intelligence.

Functions of the Corpora Quadrigemina. — Experiments upon these organs are difficult on account of their small size and deep situation in the brain. The evidence from lesions produced upon the lower animals has for a considerable time tended to connect the corpora quadrigemina with sensory impulses, not to say sensations, of sight. Extirpation on one side appears to cause blindness of the opposite eye; and the amount of blindness is different in different animals, as the decussation of the fibres in the optic chiasm is more or less complete in different animals. Moreover, when the brain is removed in front of these organs, and they are themselves left intact, the animal can still guide and co-ordinate its motions in response to visual impulses. The reason for all this is not quite clear. It may be that destruction of the nervous substance in this region abolishes those movements of the muscles, in response to the stimulation of light, which involve complicated co-ordinations with other excitations of sense, or with earlier established experience. We agree with the remark of Eckhard, that much of the functions commonly attributed to these bodies should be ascribed rather to the *region* in which they lie.

Certain disturbances of motion and impairment of the power of co-ordination of the muscles controlling the face, eyes, trunk, and limbs, follow injury or extirpation of the corpora quadrigemina. But this effect also is probably largely due to the irritation and lesion of the surrounding nerve-tracts. While, then, these organs are connected with the cerebellum, pons, and medulla, in securing equipoise and precision of movement, it is scarcely safe to attempt a more precise localization of their motor functions.

Functions of the Optic Thalami. — Some special relation of the optic thalami to impressions of sight is generally admitted. The fact that animals deprived of their cerebral hemispheres alone are capable of adjusting their movements, in a complicated way, to visual impulses, seems to indicate that the mechanism of these organs is associated with the corpora quadrigemina in performing this function. Disturbances of vision, sometimes amounting to complete blindness, have been observed in human patients as the apparent result of disease of these organs. Some observers, as Dr. Ferrier, and even Wundt, have connected the optic thalami with the regulation of the muscles in response to sensations of touch. The evidence on which this conclusion is based is, however, very doubtful. And, indeed, the part which they appear to play in the reflex-motor and automatic mechanism of sight may be rather due to secondary effects on the surrounding nerve-tracts. It is even now not wholly out of place to quote the remark, made some years ago by the French authority, Vulpian, "We know nothing of the *special* functions of the optic thalami."

Functions of the Striate Bodies. — The special motor significance of the corpora striata is undoubted. As Dr. Ferrier has maintained, the rule is, that stimulation or destruction of these organs in man and in the monkey causes results almost exactly like those obtained by the same treatment of the motor centres of the cerebral hemispheres. Lesions of the striate bodies, in the case of the animals, are usually followed by laming of the limbs of the opposite side. This result does not, however, always occur. In man, paralysis of the arms and legs of the opposite side follows disease of one of these organs. And yet a case has recently been reported[1] where destruction of the anterior and inner parts of the striate bodies on both sides was followed by no paralysis of the limbs.

While, then, there is much evidence for the view of Wundt, who considers these ganglia to be organs preeminently for the co-ordination of those motor impulses which are derived from the cerebellum and the cerebrum,

[1] In Brain, July, 1887.

we cannot affirm, without qualification, that the striate bodies are exclusively motor and the optic thalami exclusively sensory.

In 1884 J. Ott pointed out that cutting the corpora striata is speedily followed by a marked rise of temperature. Other experimenters also have discovered proofs that these bodies are in some special sense "fever-centres," cerebral areas in special connection with the vaso-motor system.

Gray Matter of the Third Ventricle. — Important central functions appear to belong to the nervous substance which lines the floor and walls of the third ventricle. One experimenter (Bechterew) finds evidence, as he thinks, that this substance operates in connection with the olivary bodies for the co-ordination of motor impulses with sensory impulses of touch, and with the semi-circular canals in response to sensory impulses of sound. There seems no doubt that the matter around the third ventricle is of importance in co-ordinating movements necessary to the equipoise of the body through impulses derived from changes in the axial direction of the eyes.

It thus appears — to repeat from our advanced point of view what has already been indicated — that *all the central organs lying between the cerebral hemispheres and the medulla oblongata are engaged in the general function of co-ordinating, in a highly complicated way, the movements of the muscles with the sensory impulses of the special organs of sense.* In the normal condition this function is under the control of the hemispheres of the brain. The separate organs form a complex interrelated system, corresponding to the complex psychical life of motion in response to sensation. In general, even in the case of the lower animals, the functions of these organs, when bereft of the cerebral hemispheres, shows a lack of *psychical quality*, of conscious, and especially of intelligent, feeling, desire, and planning.

It is quite purely "automatic" (in the narrow sense of the word), — the reaction, without intelligence, upon internal and external stimuli of a highly complicated physical mechanism.

CHAPTER VII.

MECHANICAL THEORY OF THE NERVOUS SYSTEM.

THAT much of the human body exhibits the structure and movements of familiar machines, there can be no doubt. Its members support and act on each other according to those laws of the lever, pulley, ball-and-socket joint, etc., with which the science of mechanics has to deal. These laws do not need special modification when applied to the case of the body. Less obvious, but equally undoubted, is the machine-like character of certain muscular and epithelial structures. The heart, for example, is a pump with chambers and valves; and the flow of the blood through the arteries resembles that of a fluid pumped through conduits of unequal and changeable sizes. The lungs may be compared to a bellows which alternately sucks in and expels the surrounding atmosphere. So also is the pull of the tendons on the bones like that of a cord or chain attached to a mass, for its movement.

But the contraction of the muscular fibre is a very different affair from any of the movements to which reference has thus far been made. It is a vital motion brought about in the molecules of the muscular substance by the stimulus of the nervous discharge into it. Yet the living muscle may be looked upon as a molecular *mechanism.* [We choose the word "mechanism" as preferable to machine, because it does not imply the action of one rigid mass, as a mass, on another, under the known laws of mechanics.] It is a system of minute particles of matter which act upon each other at indefinitely small distances.

When any motion is set up in one part of the system, such motion is propagated according to laws that are determined by the constitution and arrangement of the particles themselves.

The basis for a mechanical theory of the nervous system has been laid in the considerations of the previous chapters. These considerations have all hitherto been such as dispose us favorably toward some mechanical theory. In the largest meaning of the word "mechanism," physical science knows of no other way to consider any system of interacting masses, or molecules, like those of the nervous system. And yet the considerations of the previous chapters have also prepared us for the statement that every mechanical theory of the nervous system must be very incomplete, and almost wholly of a tentative character. The behavior of even a small piece of nerve attached to a muscle (the so-called "muscle-nerve machine") baffles the explanations of all the students of physical science. How much more, then, an organism of the nervous sort, so infinitely complicated as the cerebro-spinal axis of man!

Our survey of physiological psychology would, however, be inexcusably incomplete, did we not set forth the more essential features of every mechanical theory of the nervous system. And the point we have now reached seems the proper one for dealing with this subject.

Chemical Theory of the Nervous System. — Little can be added to what has already been said (see pp. 15 ff.) concerning the exact chemical processes which take place in the formation of the nerve-fibres and nerve-cells, or during their functional activity. In the nervous substance, itself, however, we find the same chemical elements which exist everywhere in nature; these are, especially, the four elements, oxygen, hydrogen, nitrogen, and carbon. We have no reason to believe that the essential laws of the combination and dissolution of these elements are different in this substance from those known to have control elsewhere. The fact that the combinations are not precisely the same is to be traced back to the original constitution and development of the substance itself.

Nucleated granules in the very chemical constituents which give conditions to all the subsequent activity of the molecules, are revealed by microscopic examination of those cells from which the whole body springs. In the original living germ, with which the body begun, and in all its subsequent development, every chemical change in the nervous substance may be regarded as a movement of the physical molecules, — under conditions furnished by their constitution and previous arrangement.

All the energy expended in the movement of the body as a whole, or of any of its larger masses, originates in minute molecular changes. These changes stand, of course, in direct relation to the chemical constitution of the tissues in which they occur. As we have already seen, nervous substance holds in store a large amount of easily disposable energy. This energy is yielded freely and rapidly, if anything occurs to start the process within the system of molecules of which the substance is composed. When the molecules break up and recombine their elements in simpler but more staple forms, they render kinetic a great amount of energy which was formerly latent.

On the other hand, the chemical constitution and environment of the nervous substance are such as to place certain checks upon the process of breaking up; and to elicit and enhance the reverse process of building the substance up again into the more complex but unstable combinations. Thus kinetic energy again becomes stored for future use; and expenditure is kept within the limits of a wise and safe economy. That one and the same stimulus may facilitate both these processes involves a view of the nervous mechanism, under the general terms of a mechanical theory, to which we shall recur again.

Mechanical Theory of the Structural Forms. — No developed mechanical theory of the significance of the different forms, whether of elements or of organs of the nervous system, is as yet possible. Our mental picture of the nerve-commotions that pass from one nervous element to another (nerve-fibres or nerve-cells) does not admit of details of differentiation dependent upon minute differences of structure. In general, however, we note the relatively large size of the *motor* nerve-cells. Glimpses of possible peculiarities belonging to sensory as distinguished from motor layers or areas of nervous substance, are beginning to be obtained by histological science.

In general, the arrangement of the nervous elements into a system answers to the demands of a mechanical theory. The problem is one of *concatenating* the different physical systems of the body, and of adjusting the relations of the whole to changes in the environment. This problem demands a threefold exercise of function. The mechanism answers the problem with three sets of organs — namely, the end-organs, the more strictly conducting organs, and the central organs. The end-organs — as, for example and most strikingly, the eye or ear — are mechanical contrivances for receiving and modifying some of the forms of movement which take place outside of the body; and then for applying these modified forms of movement to peculiarly differentiated nervous cells and fibres. It is the office of the great mass of the eye to transmit and refract the light; of the greater part of the ear to transmit and condense the acoustic waves. But the nervous elements of the retina, and of the organ of Corti, change these physical processes into physiological processes.[*] This change, too, they effect as properly constructed *molecular mechanisms.*

The nerves also are mechanisms, consisting of minute particles, whose structure fits them to take up an agitation started at any point, and transmit it from molecule to molecule, in accordance with the constitution and laws of the molecular system which they constitute.

The solution of the problems in mechanism, which fall to the lot of the central organs, involves yet more complicated structures and functions. Among those problems are the following: Incoming molecular disturbances must be so modified and distributed as to occasion other disturbances outgoing along a number of definite tracts so that co-ordinated groups of muscles may contract, simultaneously or in the right sequence, in a highly complicated way. Moreover, the movements that control respiration, secretion, digestion, and the circulation of the blood and other fluids, must be united so as to work to a common end; they must also be modified as the changes in the environment require. Still further, all the natural processes must, in the central organs, be correlated with the processes of the mind. Only in this way can sensations and perceptions arise, through the action on the body of external stimuli; only in this way can perceptions, and their accompanying desires, emotions, and volitions, get expression in the physical realm, and induce changes in external things.

This indefinite and general view of the mechanical structure and functions of the nervous system obviously needs to be somewhat further expanded.

General Mechanical Office of the Nervous System. — The development of a rich and varied life, both animal and intellectual, requires a great variety of related sensations and motions. The sensations are primarily designed to give notice to the animal of changes in his environment to which his condition must be adapted by changes of his bodily parts. Within certain wide limits, the same office is performed by sensory impulses which do not give rise to *sensations*,—in the only true meaning of that word, as psychical states. But sensations, as primary psychical states, form the basis of intellectual attainment and development.

The forces of external nature continually irritate the peripheral parts of an animal's body. These forces are the stimuli of sensory impulses, only when they are converted, within the tissues of the body, into molecular motions of a physiological kind. The mechanism of the nervous system accomplishes this work of conversion; it then propagates the molecular disturbances to the proper central organs, and through them again to the external and muscular tissues of the body. Thus the play of the energies of external nature, instead of being injurious or destructive, becomes useful in maintaining the equilibrium on which life depends. It also becomes educative,—not only of a wise use of the bodily organs, but also of the higher life of the mind.

Now it is plain that all this requires a constant *equilibrating* of the interaction of different and distant parts of the body. How shall this general important office of "equilibrating" be performed? Only by a highly elaborate arrangement of an indefinitely great number of very complex molecules. Such a molecular mechanism is the nervous system. The various forms of physical energy—such as light, heat, sound, chemical change, etc.—set into molecular agitation certain nicely adapted parts of this mechanism. This agitation is propagated from place to place, along the tracks prepared, and accompanied by other physical changes of a chemical, thermic, and electrical kind. These functions of the nervous system are nothing but the movements of physical elements, whose constitution and changes, when performing their work, it is indeed very difficult to discover, but which undoubtedly have a physical constitution and which change their relations in space under laws resembling those familiar to general molecular science. But this is precisely what science understands by a "molecular mechanism."

On the other hand, it cannot be denied that such a description as the foregoing is not full and exact enough to satisfy the demands of scientific research. It is confessedly based upon conjecture; it is full of gaps and assumptions. A complete and satisfactory mechanical theory of the nervous system would have to answer a number of extremely difficult special problems, the very beginning of an answer to which has scarcely, as yet, been attained.

What, for example, is the precise nature of those chemical changes which — we have every reason to believe — go on in every nerve when it is irritated? If the process of excitement consists in the explosive decomposition successively of the elements of the nerve, what checks the process of explosion? Why is not all the energy expended by the excited nerve? How does it manage to repair itself so as to answer, within certain limits, all the demands which it is possible to make upon it? So, too, if we attempt to bring the nervous mechanism under the terms of a general electrical theory, we find a number of difficult and hitherto unanswerable problems awaiting us. How shall the phenomena of electrotonus in nerves be explained in terms of any known electrical theory? How shall we regard the so-called "natural current," etc.?

These immense and perhaps, in some instances, insuperable difficulties do not, however, excuse us from the obligation to hold firmly by the proposal to regard the nervous system under the terms of a mechanical theory. Molecular science in general — in all its different branches of heat, electricity, magnetism, etc. — encounters many and great difficulties. But it knows no other way, in fidelity to principles established by all scientific experience and by all the past development of physical science, than to face the difficulties with successive attempts to overcome them, and thus satisfy all the phenomena in terms of a *mechanical* theory. In the nervous system of man, molecular science finds its most complicated and baffling problems. These problems, too, it must continue to regard in fidelity to its most general established principles.

It only remains for us briefly to sketch several of the forms which have been taken by the attempt to frame a precise theory of the functions of the nervous mechanism.

Wave-Theory of Nervous Action. — That the molecular disturbances caused in the nervous substance by the action of stimuli move from place to place, after the analogy of waves, is shown by all the phenomena with which so-called "general nerve-physiology" attempts to deal. In particular have we seen (p. 130 f.) that the effect of several excitations of a nerve is compounded, in some sort, in the movement of the attached muscle. Those excitations which are simultaneous, or which follow each other with the right degree of rapidity, are "summed up" in the nerve, like waves of nerve-commotion piled upon one another. Besides cases of "summation," those of "interference" seem also to exist. Moreover, the effect of one excitation, in certain instances, especially within the central organs, appears to "facilitate" the subsequent passage of other excitations along the same path.

Elaborate experiments have been made to determine the laws which control the "summation," "interference," and "facilitation" of the waves of nerve-commotion within the nervous mechanism. Let the interferences be called "positive" when the currents are moving in the same direction, and "negative" when they are moving in opposite directions. Certain interferences may also be noted which have a "heightening" effect; for the result actually produced in the muscle appears to be greater than the sum of the two single effects gained by the partial excitations if uncompounded. When, on the contrary, the result is less than the sum of the separate partial excitations, the effect is said to be "depressing." When, in the third place, the result is reduced to zero, the effect is "inhibitory." All the foregoing kinds of result may be obtained by compounding the nerve-commotions. But so complicated are the phenomena derived by the various forms of compounding as to forbid our regarding the organs themselves as simple and substantially homogeneous structures. *The effects produced by wave-like "interferences" in a nerve depend upon the original molecular constitution of the nerve excited.* Moreover, in general, the results of interference conform to the same rules after decapitation or poisoning as before. The interferences that occur in reflex action also follow the same course as those which occur by direct stimulation of the motor nerves.

In brief, — even in the case of the simple nerve-muscle machine, — it is the molecular constitution of the substance, which acts as a mechanism, that determines all the many variable elements resulting from the molecular disturbance of this substance.

The phenomena which the central organs exhibit when excited are, of course, far more complex and difficult to bring under known laws of molecular wave-like impulses, than are the phenomena of the comparatively simple nerve-muscle machine. In general, the motor excitation of any extremity of an animal, from the brain, "facilitates" the subsequent passage of reflex stimulus affecting the same extremity; and, conversely, reflex stimulation of any extremity "facilitates" the passage of a subsequent motor excitation from the proper area of the brain to that extremity. For example, stimulating the toes of the fore-leg of a rabbit produces a greater reflex movement of the same leg, with the same amount of stimulus, if the cerebral motor-centre for that leg has just been directly stimulated. Different reflex excitations may also be made to "assist" each other in a similar way. But by this method of experiment, also, certain results of compounding excitations are attained which seem incompatible with any known theory of the summation or interference of molecular wave-like disturbances.

Strictly speaking, we cannot represent, without qualification, the behavior of a single nerve under stimulation from two currents of electricity acting upon it in combination, as though it were an affair of the "addition" or "subtraction" of their separate effects. It is possible that a stimulation equal in amount to $a + b$ may not excite the nerve, although one equal to b alone will excite it, in case a current equal to a has just previously been acting in the nerve. Excitations already existing in a nerve, when further stimulation is applied, are then not simply *added to* or *subtracted from* the latter. They rather tend to produce obscure molecular changes in the nerve itself, and these changes show themselves, in the nerve, in a very variable and baffling way, as places and phases of exalted or depressed excitability. Let a represent the strength of current required to excite a nerve in its normal condition. When the *nerve itself* is in the condition of exalted excitability, a current weaker than a will excite it; but when it is in the condition of depressed excitability, a current stronger than a will not excite it.

How obscure and complicated are the molecular conditions connected with the excitement of a nerve, is further shown by observing the effect of cross-section upon its behavior. For example, for some minutes after cross-section, binding the nerve produces a large increase of its excitability in the injured place. This is true for all kinds of stimuli, including the electrical current in both directions. Five to ten minutes subsequently, however, the making of the current in the opposite direction to the current induced by cross-section frequently has a diminished rather than an increased effect.

Electrical Theory of Nervous Action. — A leading authority has declared that the two most important principles which must enter into any theory that undertakes to explain the behavior of the nerves in relation to electricity are these: (1) the principle of electrical excitation, and (2) the principle of the so-called "current of action."

We have already seen (p. 127 f.), that the passage of an electrical current through a nerve produces a changed condition of excitability called *electrotonus*. It has also been shown that this condition varies in different parts of the nerve, with the distance of each part from the electrodes, and with the strength of the polarizing current. The condition is in general one of increased excitability (and perhaps decreased conductivity) around the cathode, and of diminished excitability around the anode. The time required for the development of this condition is not perceptibly later than the electrical current which occasions it. The condition seems also to spread itself over the nerve with a speed equal to that of the process of excitation.

Another important fact already noted (see p. 130), is that, with the nerve as with the muscle, the galvanometer shows the passage of a current when one of the electrodes is placed at its cut end and the other at its equator. This so-called "natural current" is diminished by stimulating the nerve, as is shown by the return of the needle toward the zero-point ("negative variation").

How now shall these two cardinal groups of facts be explained in terms of a defensible electrical theory? The question cannot, at present, be answered with all the accuracy and detail which physical science requires. Considerable progress has, however, been made toward a probable answer to several of the particular inquiries involved.

Theory of the so-called "Natural Current." — Two ways of regarding the phenomena referred to above as the "natural nerve-current," or "current of rest," have been proposed. An intelligent choice in favor of one of them now seems possible. The first of these theories (that of du Bois-Reymond) holds that a true *natural* current exists in the nerves, previous to their excitement or injury by cross-section. This current is made obvious by the deflection of the needle of the attached galvanometer. It is then to be regarded as the resultant of the innumerable unobserved currents belonging to the separate molecules of the nerve. To account for the latter, an elaborate theory is proposed, which regards every molecule of the nerve as a minute battery with positive and negative poles. It is the presence of these molecules which gives rise to currents in the medium that surrounds them.

In order to account for the fact that such "natural" currents are exceedingly small or wholly wanting, when the structure is *uninjured*, this theory is obliged to resort to very complicated and artificial hypotheses. Under this weight it may be said utterly to break down.

The rival theory (advocated especially by Hermann) denies the existence of any true "current of rest" in uninjured nerves. It regards the starting of the current as due to the injury inflicted by cross-section. For, whenever a nerve is cut or any of its fibres injured, the molecules at once begin to die. But this implies chemical and other changes. These changes, in which the death of the molecules consists, develop the electrical currents. *The molecules, disturbed by the injury, become negative toward the uninjured parts.*

Instead, then, of seeking an elaborate special explanation for the phenomena of "negative variation," we may hold that they are precisely what we should expect in view of our knowledge of general electrical theory. So-called "negative variation" is not due to the diminution of a current previously existing. It is simply a manifestation of the electro-motive forces which come into action at the moment and at the seat of excitation. As this wave passes along the nerve, each minute portion of the nerve becomes, first, negative, and then positive, toward the adjoining portions. The resultant of these small local currents is an excess of those *from* the cut end over those *to* the cut end, —that is, the so-called negative variation.

Thus the phenomena of the "natural current" and "negative variation," so called, are all to be brought under the one general principle. *All excitable protoplasm, when dying or irritated, becomes negative towards its own uninjured and unirritated parts.*

Theory of the Electrotonus of Nerves. — It has been said that any electrical theory of the action of the nervous substance must be prepared to explain the phenomena of changed excitability produced by the constant current in the nerve. The point of starting for that form of theory, which has most claims to credence, may be taken from a discovery made some years ago by Matteucci. In 1863 this truly great investigator noticed phenomena, similar to those of the nerve in the electrotonic condition, occurring in over-spun wires when moistened with a conducting fluid. If an electrical current be applied to the moist covering of such a wire, every part of the wire will develop a current flowing in the same direction with the primary current, but with its strength diminishing as the distance increases from the points where the primary current is applied. No such current arises, however, if the wire is made of amalgamated zinc, and its covering is moistened with a solution of sulphate of zinc. It appears, then, that the changed electrical condition of the wire depends upon the limiting surfaces of its metal centre and its moistened covering being polarizable. That is to say, as has been more recently maintained,[1] a conductor consisting of a centre and a conducting covering, with polarizable limiting surfaces, as soon as a momentary electrical current is sent through any portion of it, begins successively to exhibit a current of the same kind at every other place in it.

Can a nerve be regarded as having the properties of the over-spun wire, with its polarizable limiting surfaces? Every nerve-fibre may certainly be said to consist of a centre and a covering substance. The needed limiting surfaces may, perhaps, be found between the axis-cylinder and the medullary sheath. An inner polarization, such as takes place between the wire and its moistened covering, may then take place between this core of the nerve and one of its sheaths. The electrotonic current may, therefore, be due to an escape of this polarizing current. Such a current is wanting in dead nerves, because the requisite inner polarization cannot take place in dead nerves.

Various objections have been brought against an electrical theory of the nerve as formed after the analogy of the over-spun polarizable wire. Some of these objections are based upon very complicated results which are gained by stimulating the nerve under a variety of conditions, and with the exciting current applied to different parts of the nerve, — intra-polar as well as extra-polar. To explain these results it seems necessary to suppose that a number of "secondary action-currents" are evoked by the stimulus; and that these currents are superimposed upon one another, and upon the electrotonic variations due to the polarizing current — all in a bewildering complexity of combinations. But — with the condition of the Ptolemaic system just previous to the discovery of Copernicus in mind — we feel obliged for the present to stop and await conjectures warranted by further researches.

It is perfectly obvious that "the platinum wire, with its moist sheaths, is no (complete) model of the irritable nerve." A single nerve-muscle preparation, taken from the leg of a frog, behaves in such a way as to show that it is, even as regards its electrical properties, a much more complicated mechanism than is any such wire. We must confess, then, that we have no adequate theory for explaining the behavior of this comparatively simple nervous apparatus. How far, then, are we from a complete mechanical theory of the human nervous system! Any statement of an intelligent and judicious attempt to form such a theory possesses, however, a certain interest and value.

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[1] By Hermann, in Pflüger's Archiv, 1885, xxxv., p. 23 f.

Mechanical Theory of Wundt.—In the attempt to consider the nervous system as a molecular mechanism we are obliged to reason, for the most part, deductively. We cannot successfully investigate directly the chemical and physical constitution of the nervous elements, and the changes which they undergo in the discharge of their functions. By assuming certain general principles of molecular physics, and especially the law of the conservation of energy, we can speculatively show how living beings may be brought under the control of these principles. This is the mode of procedure adopted by the German authority, Professor Wundt.

All living beings take a noteworthy part in that process of interchanging potential and kinetic (inner and external) energy, which goes on everywhere in nature. In all animals which have a nervous system, it is this system which controls the process. The process itself is a species of combustion. The source of the peculiar activities of the nervous system in controlling this process lies in the nature of the chemical combinations found in its substance.

The nervous system, regarded as unaffected by stimuli, may be theoretically compared to a fluid in a condition of equilibrium. In fact, however, the nervous system never is in a condition of *perfect* equilibrium. Not only is there a ceaseless play of energy internal to the system, in which the atoms separate from their old combinations as nervous substance and reunite, in new combinations, to form the same kind of substance; but also a continuous process goes on by which the molecules of the nervous substance are broken up to form less complex but more stable non-nervous compounds. The reverse of this last process is also constantly going on in the body; the nervous system is being nourished, or built up, by the more stable compounds of other substance being broken up and their atoms used to form the nervous substance.

Here, then, are two processes of change constantly going on. One represents the passing of the atoms from the less stable to the more stable combinations, the destruction of the nervous substance, and the setting free of stored or potential energy. The energy thus made apparent Wundt calls "positive." The other process represents the passing of the atoms from the more stable to the more highly complex but less stable combinations, the repair of the nervous tissue, the storing of energy and the vanishing of kinetic energy. The energy stored up, when the more stable combination vanishes, is called "negative." The positive molecular energy of the nervous system is recognized as heat set free, as contraction of the muscles, etc.; its negative molecular energy exists in the form of heat becoming latent, or of inhibitory action upon the course of the excitation of the nerves, etc.

Wundt would explain the process of excitation and conduction in the nerves, in accordance with the foregoing theory of positive and negative molecular energy. In all cases, when a nerve is excited, two classes of opposed effects are set up in its substance. One is directed toward the production of external energy, — such as secretion, stimulation of ganglion-cells, movement of the muscles, etc. The other is directed toward the control of the energy thus set free. The general law is, that *by the application of stimulus both of these opposed effects are augmented in the nervous substance.* That is to say, irritating the nervous substance accelerates both the recombination of the atoms of its highly complex molecules in less complex but more stable forms; and also the escape of the atoms from these forms and their return to the more complex and less stable combinations. The work which the nerve does external to itself depends upon the former process. It is a species of combustion, in which the complex molecules break up and their atoms pass into more stable and simple combinations. It involves, of course, the exhaustion of the nerve. It implies that the positive molecular energy is more accelerated than the negative, by the irritation of the stimulus. The entire sum of energy thus set free to do external work is distributed in three principal directions: in the continuous excitation of the nerve; in producing heat; in producing the reverse process of negative molecular energy.

Wundt's theory becomes more complicated when he attempts to apply it to the central organs of the nervous system. Here the chief thing of which account must be taken is the observed fact that a greater amount of stimulus is needed to move a muscle *through* a collection of ganglion-cells. The nervous substance of the central organs offers a greater resistance to the progress of a nerve-commotion than is offered by the nerves. On the other hand, this substance has stored within it a vast amount of energy; it is, therefore, in a condition to answer a demand made upon it by developing a far greater amount of work. Wundt finds proofs for this view in the phenomena of "reflex poisons," of "summation," of "inhibition" (see p. 165 f.), etc. He concludes that when summation takes place, the several sensory excitations have been conducted in the brain to different sensory regions, and have then passed simultaneously from them into the corresponding motor elements of the central organ. But when inhibition takes place, the excitations have been conducted so as to come together and counteract each other in the same sensory central region.

Excitation of the central organs, like irritation of the nerves, increases both their positive and their negative nervous energy. But the positive molecular energy of the central organs is but slightly increased by a momentary excitation. Prolonged excitation, however, causes the positive condition — *i.e.* the condition of doing work external to the system — to predominate over a wide area. In the nerve, as a rule, the nervous substance is used up, and the process of restoring it and storing energy goes on, comparatively slowly. An excited ganglion-cell is in a condition analogous to that of the nerve at the anode when the constant current is passing through it. In the cells, as a rule, the production of the complex molecules in which energy is stored predominates.

The fundamental properties of nervous matter considered from the mechanical point of view are, according to Wundt, these two, (1) to receive external impressions, in order by them to be determined in its own molecular condition; and (2) to transform the potential energy of the body into kinetic, partly under the immediate, and partly under the progressive, influence of these impressions.

Wundt proposes an elaborate and highly speculative view of the molecular constitution and functions of the ganglion-cells. But we refrain from entering upon a subject so largely conjectural.

In conclusion, we return to the general truth that the entire nervous system may undoubtedly be regarded as a vastly complicated molecular mechanism. Its chemical constitution is highly complex and correspondingly unstable. It performs, as a mechanism, the general work of bringing together into unity the functions of the other systems of the body. It performs this work under the laws of molecular physics. But *what it does* by way of function depends upon *what it is* in respect to molecular constitution. And so complicated is the application to it of the general theory of molecular physics that, thus far, all the resources of that science have been quite insufficient to afford detailed explanations.

CHAPTER VIII.

SENSORY AND MOTOR FUNCTIONS OF THE CEREBRAL HEMISPHERES.

ORDINARY observation does not make known to us the great significance of the nervous system for the life of conscious sensation and motion. It is only accident or the dissecting-knife which exposes the peripheral nerves to our sight. In the case of the central organs, and especially in the case of the contents of the skull, there is little in our daily experience which leads to the suspicion of their significance or even of their existence. That mechanism of nerve-fibres and nerve-cells, on whose activity all our knowledge of things, including our own bodies, is dependent, does not convey any direct knowledge of itself.

It is not so strange, then, as might appear at first sight, that the ancients, as a rule, attached little importance to the brain. The physician Alcmæon is, indeed, reported by later writers to have regarded it as the meeting-place of the senses. A similar view is ascribed to the celebrated Hippocrates, and was accepted by Plato. But Aristotle, the greatest of all inductive philosophers in antiquity, although he was the son of a physician, and was for his time exceedingly well acquainted with the dissection of animals, made little account of the brain. He seems to have regarded it as quite unfit to be the seat of the *sensus communis*, — a lump of cold substance chiefly useful as a source of fluid for lubricating the eyes!

Nor can the great significance which modern science attributes to the brain be held to have its origin largely in direct feelings connected with the exercise of its functions.

To be sure, we localize in the head certain phenomena of consciousness connected closely with processes of thought. The act of attention, for example, results in feelings of strain in the muscles of the eye, or over the skin of the forehead and its adjacent parts. Sensations of hearing, smelling, and tasting originate in the head, and sometimes seem to penetrate its interior. After-images, or spectra, appear with the eyes closed as seated in the upper front part of the face. We "talk to ourselves" within the head, as it were. Eager and concentrated observation, or concentrated reflection, may develop painful feelings in the cerebral region. Men lean the head on the hand in support of meditation; or rub it vigorously to awaken the powers of memory or reasoning. In this highly "nervous" age, the attention of multitudes is undoubtedly directed to the existence of sensations localized on the surface of, or within, the skull, which were scarcely noticed by the ancients. It was the effect of strong passion and desire on the visceral organs which attracted the attention of the latter, as all their language shows. The *brain*, in the popular estimate as a matter of seemingly direct knowledge, is a modern organ.

The phenomena of self-consciousness are confirmed in a general way by observation of what happens to others. A blow upon the head, or the shutting off of the blood-supply by pressure at the neck, disturbs or suspends consciousness. Several of the principal organs of sense, regarded as avenues for sensory impulses, are so related to the contents of the cranial cavity as to suggest that it may serve as their common place of meeting. It was this obvious fact, naïvely interpreted, which led certain ancient anatomists, like Galen and Herophilus, to locate the soul in the brain.

Modern science is, of course, not satisfied with the vague results derived from feeling and ordinary observation of others. It attempts to establish definitely and experimentally the function of the contents of the cranial cavity in the life of consciousness. In this attempt it considers, first, certain general facts which connect the entire brain of man, and especially the cerebral hemispheres, with his psychical life. It then tries to assign the more particular functions, connected with the varieties of this psychical life, to particular parts of the hemispheres. This investigation leads to "the localization of cerebral functions."

GENERAL SIGNIFICANCE OF THE BRAIN FOR THE PSYCHICAL LIFE.

A multitude of physical considerations place beyond doubt the supreme influence of the human brain upon the phenomena of consciousness.

Consciousness and the Cranial Blood-supply. — The free circulation of arterial blood, with its supply of oxygen, is necessary to the central organs for the proper fulfilment of their functions. It has been calculated that, while the weight of the entire encephalon is about one forty-fifth of the body, the supply of blood used up in the encephalon is about one-eighth or one-ninth of that required by the whole body. The presence of impurities in the blood, derived from drugs or otherwise, quickly and profoundly makes itself felt in modifying the phenomena of consciousness. The quickening of the circulation by alcohol or quinine is productive of an increased speed of the train of thought and imagination.

Consciousness and the Temperature of the Brain. — It has been known for some time that a rise and fall of temperature in the substance of the brain is connected with changes of the psychical states. Experiments upon the lower animals lead one observer to conclude that, in the case of any animal which enjoys integrity of the nervous centres, all the sensory impressions which arrive at the hemispheres produce a rise of temperature by their very transmission. But, furthermore, psychical activity, independently of the sensory impressions, develops a certain degree of heat in addition to that developed by the impressions themselves.

More recent experiments seem to show that strong impressions do not, as a rule, result in a simple rise of temperature in the cerebral areas, but rather in an alternation of rising and falling. This alternation occurs over the entire area of the hemispheres, but with different speed and degrees of augmentation in the different local areas. The elevation is greatest in the occipital protuberance; and it is greater and more rapid for emotional disturbance than for sensation or intellectual work. A variation, but of a considerably less degree, takes place in the temperature of the brain-substance even in states of cerebral repose.

The conclusion seems warranted that these changes of cerebral temperature are not due simply to changes in the arterial circulation. They appear independent of the rhythm of respiration, but dependent on the rhythm of metabolic activity. They show — that is — that *work is being done in the nervous substance in connection with the increased psychical activity.*

Consciousness and the Waste of Brain-substance. — An increase in the gross waste of tissue can be shown to be the accompaniment and physical correlate of mental work. This waste is indicative of brain-work. It shows that potential energy of the nervous substance has become kinetic. The quantity of sulphates and phosphates excreted, in comparison with the quantity carefully estimated as entering into the diet, is noticeably increased by increasing the mental work. To yield these sulphates and phosphates, the highly complex compounds of the phosphorized constituents of the brain have been disorganized.

Size of Brain in Different Animals. — A comparison of the brains of different animals shows a certain general agreement between their size and structure and the mental development of the same animals. A rough relation between the size of an animal's brain, relative to the weight of his entire body, and the animal's place in the scale of general intelligence, may then be claimed. The following table — compiled by Exner on the basis of the works of Carus and J. Müller — exhibits this relation: —

Tunny-fish	1:37,440	Finch	1:231
Land Tortoise	1: 2,240	Eagle	1:160
Shad	1: 1,837	Pigeon	1:104
Tadpole	1: 720	Rat	1: 82
Elephant	1: 500	Gibbon	1: 48
Salamander	1: 380	Young Cat	1: 39
Sheep	1: 351	Sai-Ape	1: 25

Fault may, indeed, be found with the estimates of this table; and, even if they are accepted, they show several marked exceptions to the rule they are intended to establish. For example, no one would think of placing the elephant, in intelligence, behind the salamander and the sheep. The rule itself holds only in a loose and indefinite way.

Growth of the Brain. — The brain grows with great rapidity for the first few years of the infant's life. At birth its weight, as compared with the rest of the body, is, in the male about 1 to 5.85, in the female about 1 to 6.50. The increase in the weight of the rest of the body is relatively so much greater that by the end of the second year, the brain is about 1:14 of the body's weight; by the end of the third year 1:18. It increases in absolute weight until well on into middle life; but after middle life it diminishes at about the average rate of 1 oz. in ten years. It is only in a general and indefinite way that we can claim that the growth of the brain in size corresponds with the development of the psychical life.

Weight of the Brains of Individual Men. — The average weight of the brain of the adult European is, for the male, from 46 to 52 oz.; for the female, 42 to 46 oz. Many human brains rise above the upper average ranges, and some fall below the lower average ranges, without marked mental peculiarities being connected with these variations. Numerous instances of large excess of the average weight of brain on the part of men of unusual intelligence have been recorded. For example, the brain of Byron was scarcely under 79 oz.; Cromwell, 78.8 oz.; Cuvier, 64.5 oz.; Webster, 53.5 oz. On the other hand, persons of unusual intelligence have occasionally been found to have brains of size below the lower average just mentioned. And numerous men with big heads and no corresponding growth of mental capacity are to be noted by any observer.

The brains of the insane are not, on the average, below those of the sane in weight. Idiots, on the contrary, as a rule, have brains far below the average weight; and, conversely, a brain of only 30 oz., or under, in an adult, indicates decided lack of mental capacity, if not complete idiocy. Most of such unfortunates are cases of arrested cerebral and, therefore, mental development. It may be said, then, that a certain size or development of brain-mass is necessary to average intelligence; and that an unusual but healthy development of the brain's size is favorable, but not necessary, to unusual mental activity.

Brains of Different Races. — Many data have been gathered to show that the average weight of the brains of the different races is indicative of their place in the scale of human intelligence. Most of these data are lacking in the requisite scientific exactness. The calculations have been made for the most part from the size of the cranial cavity as ascertained by measuring a large number of skulls. In this way it is inferred that the average weight of brain in the African, Australian, and Oceanic races falls from 1 oz.

to 4 oz. below that of the more highly civilized European. The weight of brain among the Chinese, however, has been calculated to be about that of the Caucasian race in Europe. The low weight of the brain of the Hindus is a function of their smaller bulk of body. Among savage races there seems to be a great lack of cases rising up to or above the higher ranges of the weight of the brain as found in European races. On this evidence, also, our conclusions must remain only general and tentative.

Relative Development of the Hemispheres in Man. — On comparing the brains of different animals the conviction becomes irresistible that the development of the expanded and convoluted cerebral hemispheres forms a certain measure of the quantity and quality of the animal's psychical life. This development, in size, number, and depth, of the cerebral convolutions, is the most distinctive feature of the human brain. In fishes, generally, both cerebrum and cerebellum are small; but there is relatively an enormous development of the ganglia connected with the organs of sense. In amphibia the cerebral hemispheres are relatively enlarged; in reptiles they are pushed still farther backward; while in birds the vesicles of the mid-brain are partially hidden by the development of the hemispheres. In the lower mammals this process of development is continued; but it is only in the higher mammals that the occipital lobe enlarges backward so as to cover mid-brain, cerebellum, and medulla oblongata; and that the fore-brain so enlarges and pushes forward as to constitute a true forehead.

Moreover, the forms of brain found permanently in the lower animals are extremely similar to those shown in succession by the development of the embryo of the higher mammals, and especially of man. This higher evolution of the brain-mantle, as it appears in man, is not attained without many breaks in the animal series. But through the process of its evolution the position and structure of the ganglia of the trunk remain in general the same, though decreasing in relative importance with the increase in the size of the mantle. Thus does comparative anatomy display the supreme significance for the psychical life of the cerebral hemispheres.

We should not be true to all the facts, however, if we did not admit that, in each great group of animals, variations occur in the degree of cerebral convolution, such that it cannot be said accurately to measure every ascending degree of intelligence. The ruminants, for example, although rather dull, have numerous and deep convolutions. The marmoset shows a relatively smooth and non-convoluted surface when compared with other monkeys no more intelligent.

Individual Differences of the Cerebral Convolutions. — The attempt has been made to show that the brains of less highly intellectual races, or individuals, among men are relatively poor in cerebral convolutions. The attempt indicates perhaps a probable truth; but it has not as yet succeeded in giving us a scientific certainty. The brains of idiots (or cases of arrested development) are, no doubt, often poor in convolutions. We have already seen that an almost infinite variety exists in the minutiæ of the arrangement of the gyri and sulci of the human brain. But marked anomalies in the shape of the head, and in the cerebral convolutions — especially upon the left hemisphere — are said to be more frequent among the mentally disordered.

Into other more elaborate attempts to fix standards for a scale of brain development that shall measure psychical activity and development, we do not think it wise to enter.

SPECIAL SIGNIFICANCE OF THE CEREBRAL HEMISPHERES IN MAN.

The facts and conclusions to which reference has just been made show that the general significance of the brain for the psychical life of man, in common with all the animals, cannot be doubted. They also indicate that, in man's case, the cerebral hemispheres have a special significance. The evidence of comparative anatomy and of general physiology points to that convoluted rind of gray matter, which is the mantle of the human brain, as the physical crown of man, in comparison with all the other animals; as the physical basis, in a special way, of his superior psychical life. This indication is amply confirmed by other facts of physiology, especially of the experimental kind.

The simple spinal cord of a frog, acting as a molecular mechanism, will perform a few wonderful feats (see p. 137). Joined with the medulla oblongata, optic lobes, and other lower parts of the brain, it will show largely increased signs of a complex psychical life. But there is great doubt as to how we are to interpret these signs: whether, indeed, they are to be understood as signs of a *psychical* life at all. The purposeful movements of the cord of a decapitated frog or salamander have led some physiologists to argue that consciousness must have its seat in the cord of these animals. Plainly here, however, the argument is scarcely stronger than that which could be made to show that a conscious life has its seat in the molecules of the climbing plant, or of those living corpuscles which float in the blood, or of the cilia that move in the intestines.

A large portion of the purposeful activity of the human body is not definitely correlated with any conscious mental activity; for example, breathing, swallowing, winking, changing the posture of the body in sleep or in states of profound meditation, and even the highly complex operations involved in walking, singing, playing on musical instruments, or handling tools. In these and similar cases, the intricate purposeful play of the physical mechanism is by no means necessarily connected with a corresponding series of conscious sensations and volitions.

In proportion as the hemispheres of an animal's brain become relatively developed, not only their absolute but also their relative significance is increased. Their influence upon the movements of the animal is greater, the higher it stands in the scale of cerebral development and of intelligence. A frog or a pigeon, deprived of its hemispheres, can do what it is quite impossible for a dog or an ape to do in similar condition. Yet the most marked result of the loss of these parts of an animal's brain is the sudden and great departure of intelligence, of truly psychical or "*mind*" quality, from its life. This result is, moreover, the more marked the higher the animal stands in the scale of intelligence, whether as an individual among its own species or as a species among other kinds of animals. The more mind an animal has to lose, the more it actually seems to lose, when its cerebral hemispheres are destroyed.

On these grounds and others which have previously been considered (see Chapter VI.), we are inclined to hold that the functions connected with man's conscious psychical life are limited, almost wholly if not exclusively, to the cerebral hemispheres. Only in them is the physical basis laid, so to speak, for the life of conscious sensation and volition. Unless changes in the peripheral parts of the nervous system, and even in the lower portions of the brain, find expression in changes within the cerebral cortex, no effect in consciousness results. Conversely, all motor changes produced by changes in states of consciousness reach the lower portions of the cerebro-spinal axis, and the peripheral parts of the nervous system, through effects first realized in the cerebral cortex. *The physical basis of human consciousness is* certainly pre-eminently, and — we believe — exclusively, *the convoluted cortex of the cerebrum.*

But the cerebral cortex is an exceedingly complex organ; the rather is it a system of complex organs. It is not a homogeneous mass. Its different areas are not homogeneously constructed; they have a variety of connections and relations to the incoming sensory tracts and to the outgoing motor tracts. The question therefore arises: Have the different members of this complex system of organs different relations to definite motor activities in the peripheral regions, and to the various phenomena of conscious mental life? In other words: Have the different areas of the cerebral hemispheres all the same office and value in relation to the life of sensation and volition? This is the question of "the localization of cerebral function."

History of Discoveries in Cerebral Localization. — Notwithstanding the strong presumption in favor of a division of function among the areas of the cerebral cortex, the experimental science of cerebral localization dates back only twenty years. After the doctrines of the older school of phrenologists (Gall, Spurzheim, etc.) had fallen into disfavor, the great experimental physiologists pronounced against the localization of cerebral function. The French authorities, Longet and Flourens, for example, declared that they had irritated the cortical substance with a variety of stimuli applied to various localities, and had extirpated portions of it selected from different places, without obtaining any marked results upon the muscular movements. Meynert, indeed, put forth the opinion that the anatomical connections show the anterior portion of the cerebrum to be used for motor, and the posterior for sensory functions. Broca held to a special connection between a convolution of the frontal lobe and the use of articulate language. And in 1864 Dr. Hughlings Jackson suggested that certain convolutions superintend those delicate movements of the hands which are under the control of the mind.

It was not until 1870, however, that the doctrine of cerebral localization began to be placed upon a firm experimental basis. E. Hitzig had noticed that certain movements of the eyes and of other muscles followed application of the faradic current to the head of his patients. In company with G. Fritsch he begun to experiment by applying electricity to minute areas of the cerebral cortex of dogs, and watching the results. The notable fact was thus discovered that some areas respond to stimulation by coordinated contractions of the muscles of the opposite half of the body, while others do not; and that the motor parts lie in general to the front, the non-motor to the rear, of the convexity of the cortex. In their first announcement they indicated five so-called "motor centres."

Since the "epoch-making discovery" of Fritsch and Hitzig, many diligent and skilful investigators have been constantly at work; and the results, not only in their scientific but also in their practical bearings, — as says a recent writer, — "with the achievements of antiseptic surgery, constitute the grandest triumphs that adorn the history of the noble science and art of medicine."

Kinds of Evidence for Cerebral Localization. — Three chief lines of evidence, leading from three great groups of facts, must be considered. These are experimentation, pathology, and comparative anatomy. Each of these has its peculiar advantages and peculiar value; each has also its peculiar difficulties and dangers. The physical and chemical processes of the cerebral substance are exceedingly difficult of determination. Its nervous tracts can be only slowly marked out, and that at cost of immense and painstaking labors. Its parts are so situated as to be removed from easy observation or experiment. Disease begins and progresses here unnoticed, or is only indicated by symptoms which require the analysis of an expert. Argument from the lower animals to man can be only cautiously applied, for the likeness of the physical structures of the two is far from perfect; and as to the mental life of the other animals, we are, at the best, much in the dark. It is, then, only by the most persistent, candid, and cautious use of all three of the available kinds of evidence that a conclusion can be reached.

Evidence from Stimulation. — In the localization of cerebral function two kinds of experimentation may be employed. These are stimulation and extirpation. The immediate object of experiment by stimulation is, of course, to discover what groups of muscles can be contracted by applying irritation to definite areas of the cortex. It is assumed, then, that such areas are, either directly or indirectly, connected in some special way with the contracting groups of muscles. The most efficient and manageable stimulus is the electrical current, but mechanical and chemical irritation may be employed in certain cases.

The fact that the same intensity of the electrical current, which will call into movement definite groups of muscles, when applied to certain more or less extended areas of the cerebral cortex of man and of the other higher animals, will not excite the same movements if applied only a fraction of an inch distant from these areas, is now established beyond doubt. The interpretation of this fact, and the right to speak of these areas as "motor" areas, have, however, been disputed. It was claimed, immediately after the experiments of 1870, that the effects of the stimulus were due to extra-polar conduction of the electricity in the substance of the brain. This organ, it was said, would diffuse the electricity like any other practically homogeneous substance. It was, moreover, soon found that, if a motor area be separated from the underlying substance by a circular cut, it is excitable with only a small increase in the strength of the stimulus. Or if the gray surface be wholly removed, and the stimulus applied to the blood in the cavity, the customary result follows. From these and other facts it has been argued that these areas are not true cortical "motor centres."

In answer to objections like the foregoing the following, among other similar arguments, are urged. When the animal is deeply etherized, the excitability of the cortical regions is wholly or partly lost. This could scarcely happen if the substance of these regions acted only as a homogeneous conducting medium for the electrical current. It is also found by most observers that a stronger stimulus is necessary to move the muscles from these centres, after the gray substance of the surface has been removed. The electrical current seems also to be retarded in passing through this superficial matter; it is a fair assumption, then, that the interval is spent in evolving the particular nervous function which belongs to this matter. Indeed, that the evidence from stimulation connects certain portions of the gray surface of the brain with the movements of certain groups of muscles, in a peculiar way, is now scarcely to be denied by any one acquainted with the nature and extent of the phenomena.

Evidence from Extirpation. — It is natural to argue that those areas of the cerebral cortex, whose loss is followed by the loss or disturbance of motion in definite groups of muscles, or by the loss or disturbance of any class of sensory impressions, are functionally related in some peculiar way to such muscles or organs of sense. The argument, however, needs caution in application. For in the first place, it is impossible at each stage of the experiment to know what is the precise condition of the brain. Local and extensive inflammations, secondary lesions and degenerations of the nerve-tracts, cannot easily be followed by the experimenter in detail. It is generally found that the effects of extirpating any so-called "sensory" or "motor" area change from time to time. Not infrequently they appear to be almost wholly temporary. Among those effects that seem to be permanent, some are obviously so; but others are so delicate as almost wholly to escape observation. It is, of course, peculiarly difficult to tell just what is the nature of an animal's sensory activities; and how much of intellectual or "psychical" quality is lacking to its hearing, smelling, tasting, feeling, or seeing.

Evidence from Pathology. — It is pathology which gives us the most direct evidence for the localization of cerebral function in the case of man. We cannot burn or cut away portions of the human brain merely for purposes of experiment. Yet accident and disease destroy the different areas of its cortical substance. Such lesions, however, are rarely circumscribed nicely like those which can be made in the brain of an animal by the knife or corroding acid of the operator. They are usually accompanied by lesions in the sensory and motor tracts below the cortical substance; and this may vitiate the conclusion otherwise to be derived from them. It is only by *post-mortem*, as a rule, that the last state of the case can be exactly known. And the reports of *post-mortem* cases have hitherto — owing to the ignorance and carelessness about such matters of the average physician — been so lacking in precision as greatly to embarrass the progress of science.

The evidence from pathology has thus far been exceedingly conflicting. Gradually, however, clearer light from this source has been shed upon the important question of cerebral localization. Physicians and surgeons are, in general, becoming better acquainted with the more important facts. Even now it is possible for the skilful practitioner to relieve or cure certain diseases by surgical means directed in accordance with the newly discovered truths of cerebral localization. The investigator in physiology is, meantime, accumulating material for more extended and accurate inductions.

Evidence from Comparative Anatomy and Histology. — The comparative study of animal structure, combined with experiment by electrical irritation, shows that, on the whole, the "excito-motor areas" which may be discovered on the hemispheres of the brain increase in number and definiteness with the increase in elaborateness of structure and in general intelligence. Only traces of such areas can be found in the case of frog or pigeon; only a few areas can be doubtfully pointed out in the case of rat or guinea-pig. But the convolutions of the brains of dogs and, particularly, of the man-like apes, are much more specialized in respect to function. While then we cannot approve of the argument which transfers the map of so-called "centres" indicated for these higher animals to the cerebral hemispheres of man, we admit the principle that the probability of a correspondence in the localization of cerebral function increases with their anatomical likeness to man. Hence the superior value of experiment with the brains of monkeys.

As histology succeeds in tracing the connections of the different areas of the hemispheres with one another, and with the nerve-tracts of the lower parts of the brain and of the spinal cord, it affords evidence confirmatory or corrective of the evidence from experimentation and pathology.

Use of all the Evidence. — The detailed study of the problem of the localization of cerebral function is one of the most stimulating and instructive instances of the use of inductive methods to disentangle the truth from a confused mass of seemingly conflicting phenomena. The *proof* of the truth must combine satisfactorily the evidence from all the sources. In making the necessary induction the following course is, in our judgment, most effective.

The indications of experiment upon the cerebral hemispheres of the animals — chiefly, of course, those most closely allied to man in their cerebral structure — must first be gathered and carefully weighed. The two forms of experimentation — stimulation and extirpation — should confirm each other, in order to give the surer indications. Guided by these indications we must then seek light from human pathology. All accessible pathological cases must be sifted and those only selected for use which have the definite and trustworthy character necessary to fit them for the purposes of induction. Especially must care be taken that our theory do not neglect the consideration of *negative cases;* and even of those cases which (in themselves considered) furnish indications *contradictory* of the great body of collected cases. The corrective or confirmatory evidence of anatomy and histology may then be applied to our conclusions. Only when all the lines of evidence unite with a large and substantial agreement, if not with an absolute uniformity, can we feel the highest attainable confidence in our results.

The Argument from Negative Cases. — The first general principle, to be admitted in all attempts at a theory of the localization of cerebral function, is of a negative character. Considerable areas of the cortical substance, when stimulated, do *not* occasion any movements in the muscles of the body. Considerable portions of this substance may be destroyed and *no* appreciable loss or disturbance of any motor, sensory, or intellectual activities result. . The early researches of Fritsch and Hitzig pointed out only five spots — each one of a small fraction of an inch in diameter (2–3 mm., as a rule) — that could be definitely related to the movement of certain groups of muscles. Between and around these areas lay the much larger areas of negative result. Though the number of irritable spots on the hemispheres of the brains of the higher animals has since been considerably increased, the non-irritable portions still remain greatly in the predominance.

Large portions of the cortical substance from the brain of an animal may be removed without the operation being followed by the permanent and complete loss of any function, motor or sensory. Indeed, a few eminent observers still maintain that the nature and extent of the psychical disturbance are largely or wholly independent of the locality from which the brain substance is taken.

The negative evidence from certain cases in human pathology is even more remarkable. There are recorded many instances of large lesions in the cerebral hemispheres of man with little or no resulting mental disturbance. One authority tells of a young man who had a foreign body of four fingers' breadth square buried in his brain, and yet lived for a long time afterward in the enjoyment of all his faculties. Another communicates the case of an Italian laborer whose skull was crushed, in the right parietal region, by a stone. This patient subsequently lost so much of the substance of the brain that it was calculated the lesion must extend down to the *corpus callosum*. He, too, lived without mental impairment; but with a *laming of the limbs on the left side.*

Other remarkable cases of lesion of the brain, followed by little or no loss of psychical functions, are such as this: A man whose skull was crushed with a stone, and whose entire left hemisphere (on his death twenty days later) was found to be a disorganized mass, continued in apparently full possession of his powers of motion, sensation, and intelligence. Instances of defective brains are also on record. In one such case, the place of the right hemisphere was discovered to have been filled with a serous fluid. No peculiarities of this person's mental life were noticed; but there had been from birth *lameness of the left side of the body.*

Extensive lesions without marked disturbance of the motor or sensory functions are especially frequent in the frontal lobes. They occur, however, not very infrequently in the occipital and temporo-sphenoidal lobes. A case is recorded of an officer shot through the middle of the frontal lobes, who till death showed no signs of any kind of paralysis. The work of M. Pitres contains a large collection of cases in which these lobes have been the seat of extensive disease, without any symptoms of lunacy or of psychical disturbance. The so-called "American crowbar case" is well known. An iron bar, 3 feet 7 inches in length and 1¼ inches in diameter, passed entirely through the top of a man's head, near the sagittal suture in the frontal region. But the patient recovered in a few minutes so as to ascend a flight of stairs and give to the surgeon an intelligible account of his injury. He lived twelve and a half years afterward, with no noticeable impairment of his sensory or motor powers.

In the words of a distinguished physiologist, it must be confessed that the understanding of cases like those just mentioned "is made more difficult rather than easier by recent researches." The evidence of these negative cases is, indeed, quite too much neglected by those who make haste to erect on insufficient data a plausible theory. Indeed, the general fault of writers on the localization of cerebral functions is that they consider, as a rule, only the cases which suggest or confirm their theory; while they neglect those even more important negative cases which tend to refute, correct, or modify the theory.

And yet, a large amount of concurrent testimony from all these main sources of evidence warrants us in announcing certain positive results. A *science* of the localization of cerebral functions, in some justifiable meaning of these words, may be said to be fairly defined.

CHAPTER IX.

SENSORY AND MOTOR FUNCTIONS OF THE CEREBRAL HEMISPHERES. — *Continued.*

THE region of the brain which is especially concerned with the motor functions lies about the great central fissure, or Fissure of Rolando. More precisely, it embraces the ascending frontal convolution (*gyrus centralis anterior*), the ascending parietal (the *gyrus centralis posterior*), and the prolongation of the two on the median surface of the brain (in the *lobulus paracentralis*).

LOCALIZATION OF THE MOTOR CENTRES ON THE CEREBRAL CORTEX.

Areas excitable by Stimulation. — The original experiments of Fritsch and Hitzig located five areas on the cere-

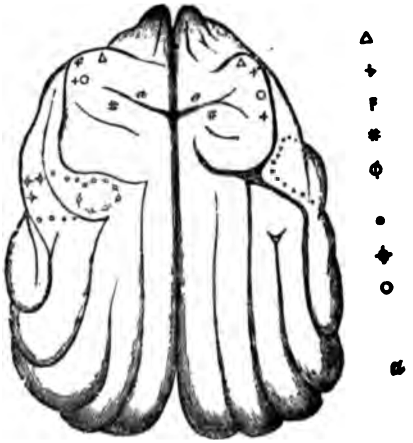

FIG. 63. — Hitzig's Motor Areas on the Cortex of the Dog. The left hemisphere belongs to one animal, the right to another; *a*, the *sulcus cruciatus*, around which the gyrus sigmoideus bends; 0000, area for the face. The other symbols are explained in the text.

bral hemispheres of the dog, which responded to irritation with the movement of definite groups of muscles. They were (1) the centre for the muscles of the neck (△ in the Fig.); (2) the centre for the extensor and adductor of the fore-limb (+); (3) the centre for the bending and rotation of the same limb (+); (4) the centre for the hind-limb (#); and (5) the facial centre (⊕ – ⊙). These investigators also obtained contractions of the muscles of the back, tail, and abdomen by stimulating interlying points, but failed definitely to circumscribe areas for these muscles.

The accompanying figure (No. 64) shows the numerous "centres of electrical irriration," which Dr. Ferrier claimed, some six years later, to have discovered on the cerebral hemispheres of the monkeys with which he has experimented. It will be noticed that these centres, like those discovered in dogs by the two German explorers, lie around the great central fissure, known in the human brain as the Fissure of Rolando.

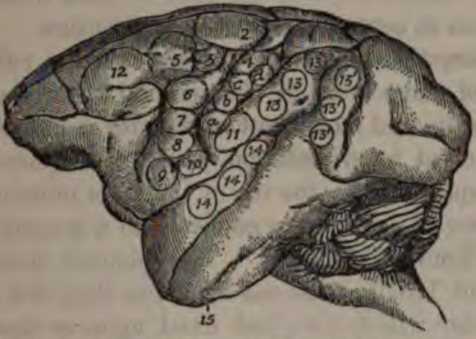

FIG. 64. — Areas on the Left Hemisphere of the Monkey, by stimulating which Ferrier obtains motion in definite groups of muscles.

Recent experiments in the attempt to establish motor centres by electrical stimulation tend to confirm the general conclusion. Some, however, have claimed that changes in the excitability of these minute areas take place; that certain ones, at first excitable, after a time cease to be so, and that others, at first not excitable, afterward become excitable. Very suggestive is the further alleged discovery that a number of minute areas for *each one* of several different groups of muscles exist in the larger "excitable zone" of the cortex. The fibres whose function it is to contract these groups of muscles would seem then to proceed directly from a number of cerebral spots belonging to each group. These minute areas for the different muscles of the extremities are said to be limited with great sharpness; they do not wholly cover each other; and those for any particular muscle are of small extent in comparison with the field or zone which may be looked upon as common to all the extremities.

The Extirpation of "Motor Centres." — As a rule, the destruction of those areas of the cerebral hemispheres, from which co-ordinated movement of definite groups of muscles can be excited by stimulation, causes a temporary or permanent impairment in the use of the same muscles. Thus the evidence of extirpation confirms, in a general way, the evidence from stimulation. The pioneer investigators, Fritsch and Hitzig, removed from two dogs the substance of the centre which they had fixed upon as that for the "right fore extremity." They observed that these animals afterward used the right fore-leg unskilfully. Since that time many observers have refined and multiplied this class of experiments in the localizing of the motor functions of the hemispheres. We now refer to some of the results thus obtained.

Experiments of Munk. — This investigator experimented, at first, by removing clean-cut circular bits about $\frac{3}{8}$ of an inch in diameter and $\frac{1}{12}$ of an inch thick from the convex surfaces of the parietal, occipital, and temporal lobes of dogs. His general conclusion was as follows: If a line be drawn from the terminal point of the Fissure of Sylvius vertically toward the falx cerebri, it will approximately mark out the limits of an anterior motor and a posterior sensory sphere.

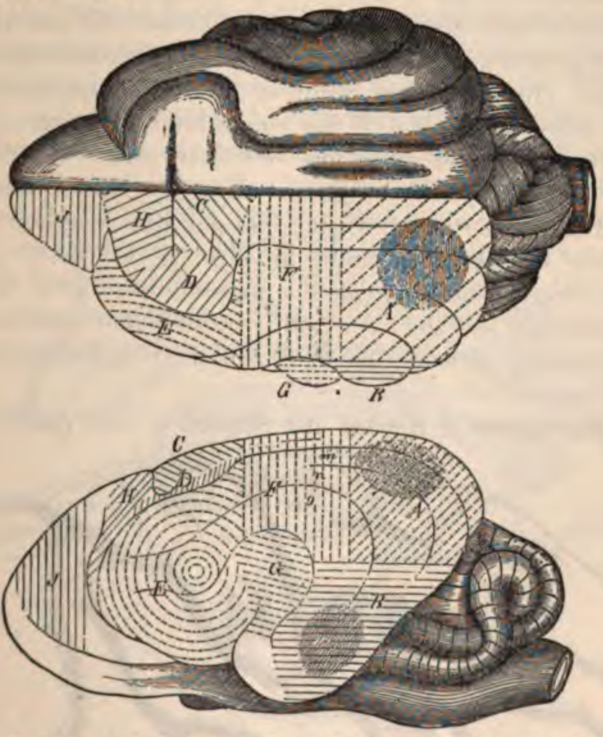

FIG. 65. — Areas on the Brain of the Dog. (According to Munk.) *A*, centre of the Eye; *B*, of the Ear; *C*, of the sensations of the hind-leg; *D*, of the fore-leg; *E*, of the Head; *F*, of the Apparatus for protecting the Eye; *G*, of the Region of the Ear; *H*, of the Neck; *J*, of the Rump.

Munk's attempts at more precise localization are indicated in the accompanying figure (No. 65). It will be noticed that three of these centres — *C*, *D*, and *E* — correspond fairly well with those fixed upon by the first experimenters in stimulation. In the regions indicated on the chart, Munk claimed to find that small and definitely circumscribed extirpations are regularly followed by definitely localized disturbances of motion.

For example, let the region *D* be removed from the left hemisphere of the brain of a dog. Then if any other of the animal's limbs be ever so lightly touched, he will heed it; but hard pressure, pinching, and sticking of the *right* fore-leg is either followed by no result, or by what seems to be only the reflex withdrawal of the leg, without attention. Moreover, the dog will suffer this limb to be placed in awkward and uncomfortable positions. He no longer handles his food with the right foot, and does not give this limb to his master on call. In running he slips on this foot. These and other phenomena led this investigator to hold that the animal had lost the "cerebral" or intelligent quality from the management of this limb, and perhaps had no mental picture of it in mind.

Experiments of Horsley and Schafer. — The value of ex-

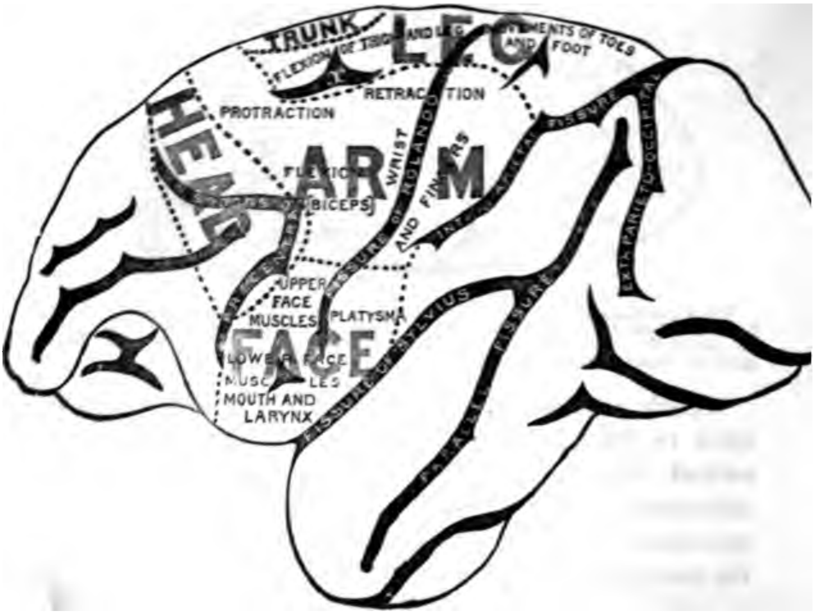

Fig. 66. — Lateral Surface of Brain of Monkey. (Taken from "Brain.")

periments by way of stimulation and extirpation upon the cerebral hemispheres of the monkey is, on account of the resemblance of this animal's brain to that of man, undoubtedly very great. Among the latest physiological researches bearing on the localization of motor centres in the cerebrum, perhaps none are more important than those of the two investigators whose names head this paragraph. Their conclusions are represented in the accompanying diagrams (Figs. 66 and 67). It must be understood, however, that all

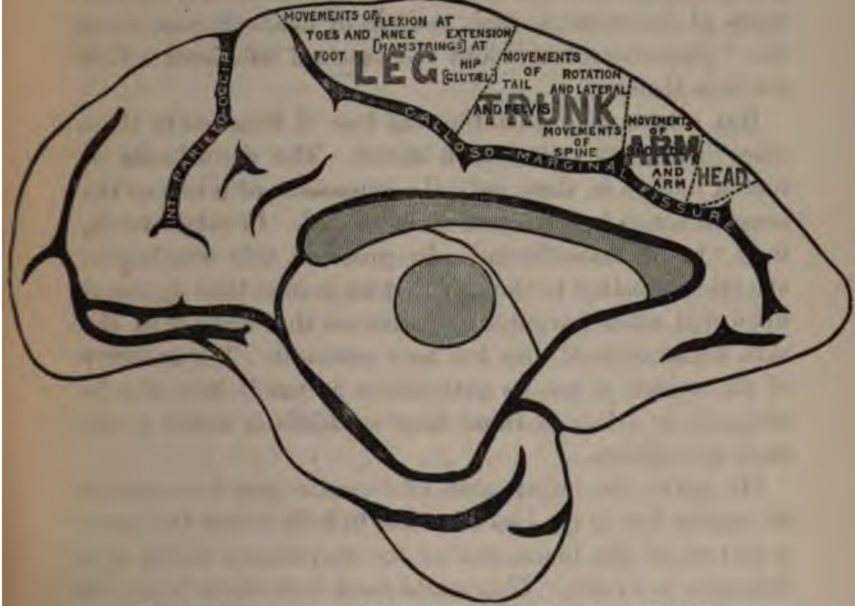
MOVEMENTS OF TOES AND FOOT
FLEXION AT KNEE [HAMSTRINGS]
EXTENSION AT HIP [GLUTÆI]
LEG
MOVEMENTS OF TAIL AND PELVIS
ROTATION AND LATERAL
TRUNK
MOVEMENTS OF SPINE
MOVEMENTS OF SHOULDER AND ARM
ARM
HEAD
CALLOSO-MARGINAL FISSURE
INT. PARIETO-OCCIP.

FIG. 67. — Median Surface of Brain of Monkey. (Taken from "Brain.")

the so-called "motor centres" marked on these diagrams have not the same evidence in their favor. Some of them await further experimental evidence. A warning must also be uttered against attempting to copy this provisional chart off, unchanged, upon the map of the *human brain*.

Interpretation of the Phenomena. — The meaning of the *apparent loss of the animal's* functions through extirpation of the so-called "motor centres" is not perfectly clear. It will always be difficult to designate precisely what factors in the complex sensory-motor activities of a dog or a monkey drop out as the result of removing a certain area of its cortical substance. Several explanations of such phenomena of motor disturbance are possible. It may be held, in the first place, that the extirpated centres are exclusively *motor;* they are, that is, the areas in which alone can originate the different efferent impulses to the groups of muscles that move the limbs. The only impairment of functions is, then, the loss of connection between the "projection-fibres" and the cerebral substance which controls them.

But others hold that the real loss of function in these cases is *sensory* rather than motor. The disturbance or loss of motion is, then, only the expression of a loss of the sense of touch in the parts to be moved. In other words, it is "tactile anæsthesia." In proof of this conclusion, attention is called to the fact that an animal thus operated upon will allow parasites to gather on that surface of the skin whose cortical area has been removed. The inability of the animal to use its extremities as hands may also be assigned to a loss of those finer sensibilities which guide such movements.

Or, again, the impairment of function may be regarded as largely due to the loss of power to hold before the mind a picture of the limbs, and of the movements which it is desirable to excite. This would seem to indicate injury to the animal's general *psychical quality*, and might involve both the sensory and the motor factors. The importance of the "association-fibres" in these cortical centres is beyond doubt. For if the centres be carefully cut round so as to sever these fibres, but not the "projection-fibres," their loss of function is almost, if not quite, as great. In fact, all the disturbances — whether sensory or motor — appear to be of the kind which indicates loss of cerebral, and so of psychical quality in the handling of the extremities, rather than the laming of any particular group of muscles. Indeed, one principal authority (Goltz) still insists that the general impairment of intelligence which results from removing any considerable amount of brain-substance, from whatever area it is taken, constitutes the most marked feature of all these cases. He finds that, although impairment of both tactile and muscular sense may temporarily occur, yet the animal by giving "increased attention" is able to feel the slightest touch on any area of the skin.

In view of all the evidence, our provisional conclusion may be expressed as follows: Certain areas of the brains of the lower animals, especially of the dog and monkey, have a special value and use in the control of the muscles of the body. These areas are situated in that region of the cortex which corresponds, in man, to the convolutions on either side of the Fissure of Rolando, and to the adjacent lobule (*lobulus paracentralis*) on the median surface of the brain. The loss or disturbance of motor function which follows injury to these areas is often due to complex mental disturbances. These are partly sensory, — impairment of the nicely shaded tactile and muscular sensations by which the animal guides its limbs; partly motor, — impairment of power to execute the volition, or realize in actual movement the mental picture of the movement and the desire to move; partly more purely psychical, — impairment of power to form complex mental images of the specific sort required, and of mental ability to take an interest in or to comprehend complex objects and situations.

In the case of the higher animals (and especially of the monkey), a further discrimination of these areas may be attempted with some success. Localization of the connected sensory and motor factors in these complex activities places the former more to the rear, and the latter more to the front, of this general area. What is true of the general area is perhaps true of the particular areas into which the general area may be divided. The broader outlines of the diagrams prepared by Horsley and Schäfer (see p. 200 f.) may be taken as indicating to human pathology its particular problems.

Our reliance must now be placed upon *Human Pathology*. And although much has been done by others in the nearly ten years since Exner's work appeared,[1] the thoroughness and carefulness of his induction entitles it to be still considered as representative of the most trustworthy conclusions.

Exner's Induction of the Motor Areas in Man. — The conclusions of this authority were based upon researches into several thousand cases of cerebral disease which had been followed by *post-mortem* examination. From this large number, 169 "test-cases" were selected. In all these cases the record was trustworthy, full, and unambiguous; and no other lesions than the one in some particular cortical area had occurred to complicate the inferences. The test-cases were tabulated on three sets of maps, according to three methods of induction: (1) Method of negative cases; (2) method of percentage; (3) method of positive cases. Thus the first map showed what areas of the cerebral cortex, if any, are *not* necessarily connected with motor or sensory functions. The second map showed the *amount of probability* that a given small area will be the seat of disease, in case this disease has been followed by a given kind of sensory or motor disturbance. [For this purpose the map was divided into 367 small quadrilateral sections.] The third map simply tabulated the cases of lesions *actu-*

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[1] Investigation into the Localization of Function in the Cerebral Hemispheres of Man. Vienna, 1881.

ally connected with observed disturbances of function, in the spots on the cortex where they occurred.

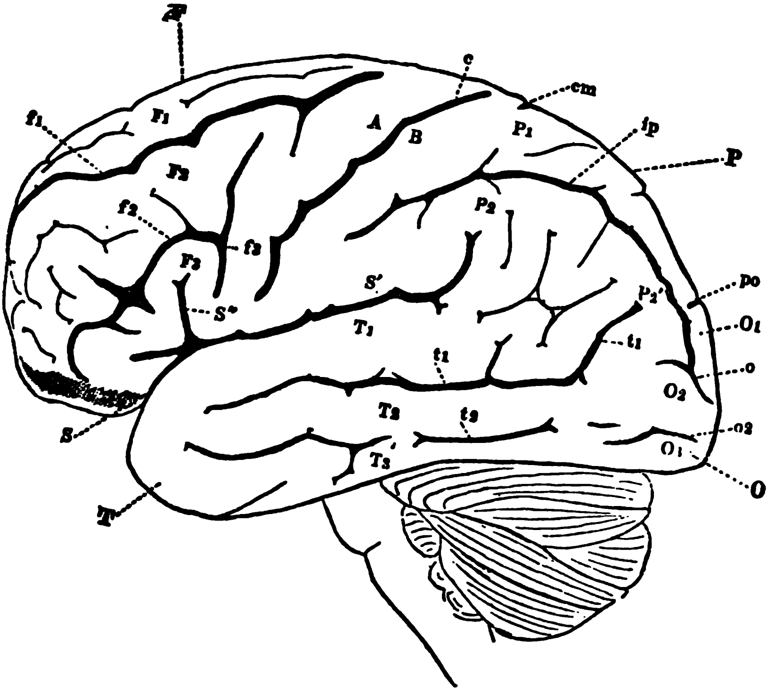

Fig. 68. — Lateral View of the Human Brain. (Schematic, Ecker.) F, frontal, P, parietal, O, occipital, and T, temporo-sphenoidal lobes. S, fissure of Sylvius, with S', the horizontal, and S'', the ascending ramus; C, sulcus centralis; A, anterior, and B, posterior, central convolutions; F1, F2, F3, superior, middle, and inferior frontal convolutions; f1, superior, f2, inferior frontal sulci; f3, sulcus præcentralis; P1, superior, and P2, inferior parietal lobule; the latter, the gyrus supra-marginalis, and P2', the gyrus angularis; ip, sulcus interparietalis; cm, end of calloso-marginal fissure; O1, O2, O3, occipital convolutions; po, parieto-occipital fissure; o, transverse, and o2, inferior longitudinal sulcus; T1, T2, T3, temporo-sphenoidal convolutions; and t1, t2, tempero-sphenoidal fissures.

Field of Latent Lesions. — In Exner's collection of cases, 20 were found in each hemisphere which had been followed by no disturbances whatever, whether of motion or of sensation. But since the collection comprised 101 lesions of the left hemisphere, and only 67 of the right, it will be seen that the chances of a lesion being *latent* (*i.e.* resulting in no disturbance of function) are much greater for the right than for the left hemisphere. On the right hemisphere the entire surface, with the exception of the two central convolutions, the paracentral lobule, and small portions of the convex and inferior surfaces of the occipital lobe, is latent. On the left hemisphere the latent field is much less extensive. This result of the induction restates the well-known fact that extensive lesions frequently occur in the frontal, temporal, and occipital lobes, without occasioning any noticeable motor or sensory disturbance.

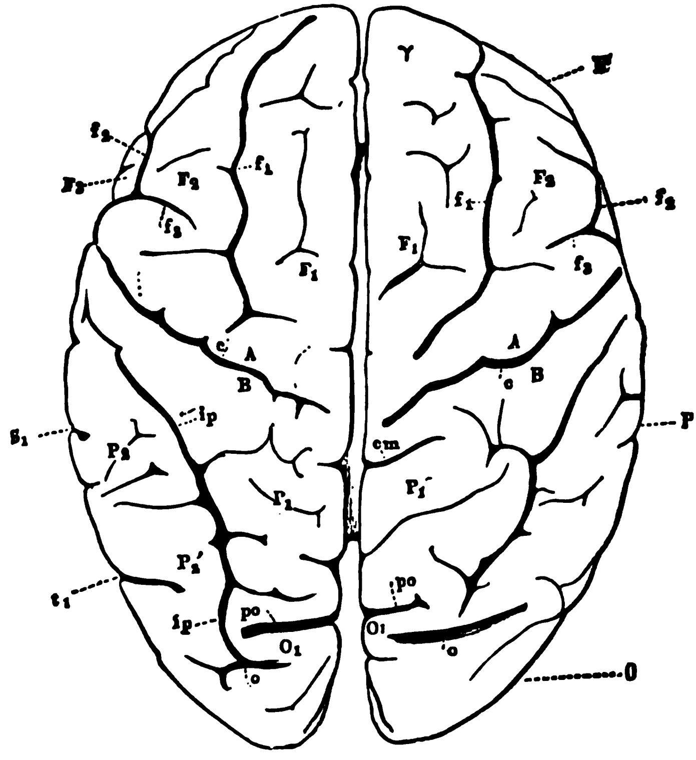

FIG. 69. — View of the Human Brain from Above. (Schematic, Ecker.) The letters have the same reference as in the preceding figure.

The regions not latent Exner divided into "absolute fields" (or areas within which no lesion occurred without the expected result) and "relative fields" (or areas in which more than fifty per cent. of the cases of lesion resulted in a disturbance of function).

Fields of the Upper Extremities. — Exner's induction from the test-cases seemed to show that the "absolute field" for the upper extremity on the right hemisphere (*i.e.* field for the left arm) includes the paracentral lobule, the anterior central convolution (with the exception of a small part of its lower end), and the upper half of the posterior central convolution. The "relative field" for the same extremity extends further, and includes the back part of the three frontal convolutions, the front part of the parietal lobe, and a considerable part of the neighboring median surface.

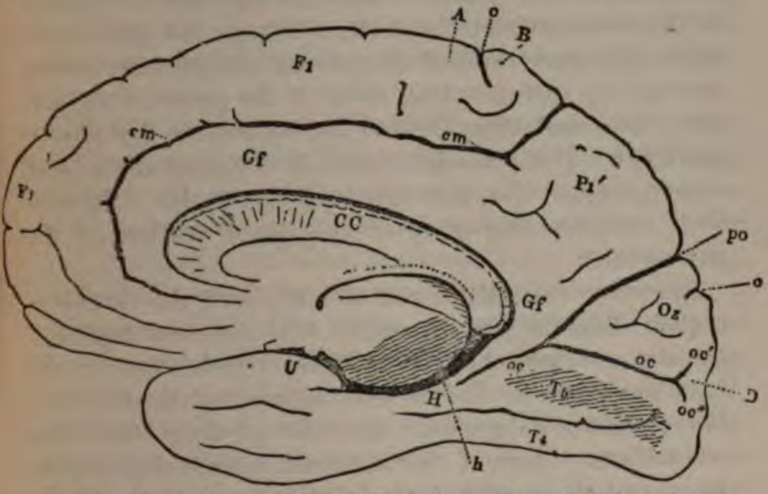

FIG. 70. — Median Aspect of the Right Hemisphere. (Schematic, Ecker.) CC, corpus callosum. Gyri: Gf, fornicatus; H, hippocampi (with its sulcus h), and U, uncinatus; P1', præcuneus; Oz, cuneus; oc, calcarine fissure, with its two rami oc' and oc". D, gyrus descendens; T4, the lateral, and T5, the medial, gyrus occipito-temporalis.

On the left hemisphere the fields for the upper extremity (*i.e.* the right arm) are more extended. Here the "absolute field" extends over the greater part of the upper parietal lobe; and perhaps over portions of the median surface of the occipital lobe. The "relative field" comprises a yet larger area of this general region of the brain. All this corresponds to the fact that, in the great majority of men, the right hand and arm are more employed for the discharge of delicate and highly intelligent functions, and therefore require a larger cerebral assistance and control.

Fields of the Lower Extremities. — Exner's induction points out, as the "absolute field" on the right hemisphere for the lower extremity (*i.e.* the left leg), the paracentral lobule, the upper third of the anterior central convolution, parts of the corresponding third of the posterior central, and some small areas, behind and below, on the *lobulus quadratus.* The "relative field" of the same limit is, of course, larger. On the left hemisphere the "absolute field" includes also most of the upper portion of the parietal lobe.

The lower extremities can scarcely have the functions of their different parts localized with the same degree of precision and amount of differentiation which belong to the upper extremities. This fact corresponds to the relatively low cerebral and psychical character of their sensations and motions. More of the brain and mind is required for the control of the arms than of the legs.

General Motor Region in Man. — The "exquisitely motor" region of the human cerebral cortex lies, then, around the Fissure of Rolando and in the paracentral lobule. It reaches over, in a somewhat indefinite way, into the adjacent parts of the frontal and parietal lobes. Besides the "motor areas" of the extremities, those for the muscles of the eyeball, tongue, head, and neck are in this same general region. For example, in nine cases of Exner's collection, in which the muscles of head and neck were affected, the lesions were all situated in one of the two central convolutions.

There can be no reasonable doubt, therefore, that the general indications, which were said to be derived from experiments with the dog and the monkey, are confirmed by human pathology. As two celebrated investigators (Charcot and Pitres) have summed up the evidence: "The cortex of the cerebral hemispheres in man may be divided, functionally, into two parts, motor and non-motor, according as destructive lesions do or do not cause permanent paralysis on the opposite side of the body. . . . The *motor zone* includes only the ascending frontal and ascending parietal convolutions and the paracentral lobule."

Further Specialization of Motor Areas. — More specific statements as to the localization of functions for small parts of the extremities, or even for particular groups of muscles, cannot be made with the same confidence. Clinical and surgical evidence is accumulating, however. For example, a case is reported, definitely connecting spasms beginning in the right lower, and extending to the right upper, limb and to the face, with a lesion in the upper third of the ascending frontal convolution on the left side; and another case, connecting cramps in the left thumb and fore-finger, spreading up the arm, with a tumor situated at the line of the junction of the lower and middle thirds of the ascending frontal and parietal convolutions.

One authority (Horsley) divides the "arm area" as follows: for the shoulder, in the upper part; the elbow, next below and behind; the wrist, next below and in front; the thumb, lowest and behind. In the area just above the superior frontal sulcus, he thinks that the movements of the lower and upper limbs are blended. Another authority (Dr. Mills) thinks that "instead of dividing the central or Rolandic Fissure into thirds, it is better, perhaps, to divide it into fourths, placing the area of representation for the lower extremity in the first fourth; that of the face in the lower fourth; and the area for the upper extremity includes the second and third fourths."

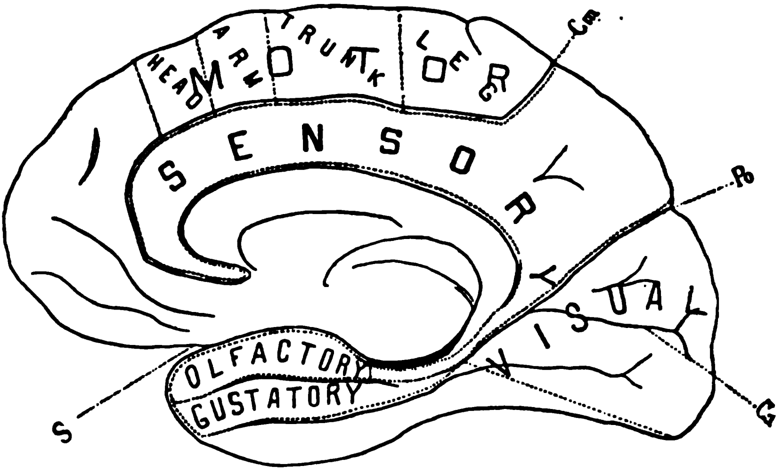

FIG. 71. — Areas of the Mesial Aspects of the Cerebrum. (Taken from "Brain.")

The accompanying diagrams (71 and 72) may be said to represent the most advanced views in the localization of cerebral motor functions in man. For this very reason, and because they are based only upon "positive cases," instead of upon an induction taking also the "negative cases" into the account, they should be received in a cautious and tentative way.

Localization of Sensations of the Skin and Muscles. — There is considerable evidence to show that the regions called "motor" are also the principal seats of those lesions of the cerebral cortex which result in loss of the sensations of touch (tactile anæsthesia) and of muscular sensations.

This has led some to hold that the so-called "motor" areas are the central representatives of the sensory impulses which originate in the skin and muscles of the same limb which is moved from these areas. For the conception of "sensory and motor centres," therefore, one authority would substitute the conception of excitable cortical areas reacting after the manner of sensitive peripheral surfaces: the true motor centres lie below. We have already seen (p. 67) that histology has attempted to distinguish motor and sensory cells in the same layer, or motor and sensory layers in the same area, of the cortical substance. The distinction is not, however, as yet established.

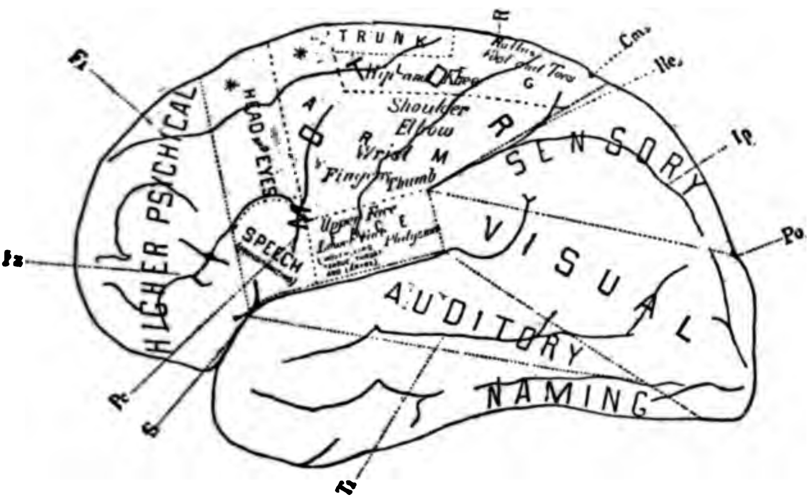

FIG. 72.—Areas of the Lateral Aspect of the Cerebrum, and Sub-divisions of the Motor Area. (Taken from "Brain.")

Human pathology has not yet succeeded in assigning an "absolute field" for tactile sensations. There is no portion of the cerebral cortex where lesions are invariably and necessarily followed by disturbances of these sensations. Exner's induction included 22 cases of marked disturbance of tactile sensations. Of these 16 were located wholly in the two central convolutions, and 3 others partly in the same convolutions. The percentage of such cases arising from injury to the right hemisphere is about twice as large as that of the left. This has led some to conclude that sensibility is the predominating function of the right hemisphere, as motion is of the left.

The *psychical* relations between disturbances of motor function and disturbances of tactile and muscular sensation are undoubtedly very complex. Physiology has not yet unravelled the corresponding cerebral relations. Perhaps we cannot do better than to conclude with one writer: There is probably a general region for sensations of touch, pain, temperature, pressure, etc., of the peripheral parts, and this region is divisible into minuter areas; these areas have close anatomical and morphological relations with the corresponding motor areas, but are probably not always wholly identical with them. So far as the two regions are not coincident, that mainly appropriated to sensory functions lies further back. It perhaps includes the gyrus fornicatus, the hippocampal convolution, the pre-cuneus, and the postero-parietal convolutions.

LOCALIZATION OF THE SENSORY CENTRES OF THE CEREBRAL CORTEX.

It requires no argument to show that experiment upon the lower animals is relatively of little value in determining the cerebral sensory centres in man. Localization of "sensory centres" so-called is in general more difficult on account, partly, of the greater complexity of the psychical phenomena and of the physical apparatus concerned. In particular, it is almost impossible to tell with confidence what are the psychical experiences, the sensory states of consciousness, of an injured dog or monkey. Yet by combining with experimentation the carefully sifted evidence of human pathology, the areas of the brain-cortex concerned in vision have been localized with approximate accuracy.

Centre of Sight according to Ferrier. — In the earlier edition of his work on the "Functions of the Brain" this investigator claimed that destruction of the *gyrus angularis* (see Fig. 68) produces loss of sight in the opposite eye; while stimulation of the same region produces movements of the eye. In a subsequent edition Dr. Ferrier has admitted his error in localizing the visual centres in this convolution to the exclusion of the occipital lobes. And further investigation seems to have shown that the *gyrus angularis* can be removed without any permanent effect whatever upon the sense of sight.

Centre of Sight according to Munk. — This investigator details the following among other phenomena which result from extirpation of the region marked A1, (see Fig. 65,) from the brain of a dog. The animal may, in general, be said to exhibit marked symptoms of "psychical blindness." By this term it is meant to say that the dog cannot form the visual images or ideas which give *meaning* to the visual impressions. It will guide itself by sight, even under difficult circumstances. But it does not *recognize* the dish from which it has been accustomed to take food, the man who has been its keeper, the threatening whip or coal of fire. If only a small area of the brain's substance is removed, it recovers psychical sight by again learning the meaning of its visual impressions. Extirpation, however, of the cortical surface somewhat widely around A1, in connection with this concentrated centre itself, results (when both hemispheres are involved) in complete and permanent "psychical blindness." Similar phenomena are obtained by Munk through experimenting upon monkeys. He concludes, therefore, that a large part of the convex surface of the occipital lobes is the seat of perceptions(?) of sight; but the visual memory-images are especially connected with the sight-centre A1.

Further Extension of Sight-centres. — Other investigators have thoroughly traversed the ground covered by the experiments and conclusions of Munk. They find that no blindness of the clear spot of vision is produced in the opposite eye by extirpating his centre A1, in the case of dogs. It is even claimed that the most extensive lesion of Munk's entire visual area does not necessarily result in the loss of the animal's vision. Moreover, it is found that disturbances of sight *may* follow lesions in the other lobes, especially in the frontal lobes. Some years since it was maintained that the *cuneus* is especially concerned, with the occipital lobes, in the functions of vision. Regions adjacent to the *cuneus* are also, on the authority of some experimenters, declared to be connected with the same functions.

The more recent experiments with stimulation by the electrical current seem to show that movements of the eyes can be obtained by irritating various areas in and around the occipital lobes. Three zones are mentioned by one authority (Schäfer): (1) the parts about the parieto-occipital fissure, connected with movement of the eyes downward; (2) the lower surface of the lobe and of the adjacent convex and mesial surfaces, connected with movements of the eyes upwards; (3) area between the two, connected with lateral movements.

The evidence from experiment with the lower animals does not, therefore, clearly and definitely indicate where pathology is to inquire for the visual areas in the case of man. The convex surface of the occipital lobes is certainly indicated in a general way. The adjacent convolutions on the same lobe and in the *cuneus*, etc., are less clearly indicated. Indeed, the most recent investigations (Lannegrace, 1889) on dogs and monkeys find hemiopia after injuries in almost any part of the cortex, and ambliopia after injuries to limited areas in the parietal and frontal lobes. How wide and somewhat scattered are the areas of the cortical surfaces which are more or less definitely concerned in all the complex phenomena of vision, even among the highest of the animals, is accordingly apparent. How much more, then, may we expect to find the same complexity of phenomena, and variety of localities involved, in the case of man!

Exner on Visual Centres in Man. — The answer of pathology to the question, What areas of the human cerebral cortex are chiefly concerned in visual sensations and perceptions? is ambiguous. The method of "negative cases," according to Exner, yields no assured results. The induction does not point out any "absolute field" of vision. But the methods of "percentage" and of "positive cases" point clearly to the occipital lobe, and especially to the upper end of the first occipital convolution (O1 in the chart, p. 205) as its most intensive portion. The region of less intensity extends over the other occipital convolutions, the *cuneus*, and the adjacent parts of the *lobulus quadratus*.

Additional Evidence from Pathology. — An increasing number of positive cases indicate that the induction just stated is substantially correct. But it still remains true that we cannot say no other areas than those mentioned above have particular connection with the phenomena of intelligent vision. One chief authority (Wilbrand) has been led to the following conclusions respecting what he calls "psychical blindness." If the impressions be cut off in their course along the optical tract, blindness, in the more ordinary sense of the word, results; but visual hallucinations, dream-visions, and subjective light-sensations are still possible. If, however, the perceptive centre (that pointed out by Munk, see p. 199 f.) be destroyed on one hemisphere, then complete cortical blindness takes place in the opposite half of the field of vision. If this centre be destroyed in both hemispheres, subjective visions, hallucinations, etc., are impossible. If the visual "memory-areas" (see p. 213 f.) be also thoroughly destroyed, then all impressions of form and color lose their psychical and intellectual character. They become unmeaning or unfamiliar impressions. We cannot vouch for the full accuracy of these distinctions. They await further confirmation.

Kinds of "Psychical Blindness." — Disturbances and loss of intelligent and appreciative sight may be due to a variety of causes, occurring either singly or combined. This fact is the expression of the variety of the cortical areas that are concerned in some part of the very complex activities of such vision as man enjoys. Thus, to adopt provisionally the classification of one writer, "psychical blindness" may be due (1) to disturbance of the organism for associating the perception of the visual object with other ideas (without disturbance of the perception itself); or (2) to disturbance of both the perceptive and the associative activity; or (3) to disturbance of the perception exclusively. Corresponding to these necessary factors in all intelligent and appreciative vision are the various cortical areas and tracts of "projection" and "association" fibres. Thus the whole apparatus of vision involves not only those areas which have been shown to be especially concerned, but also other less intensive associated areas in the parietal, temporal, and even frontal lobes.

Division of the Visual Field. — Persistent and skilful attempts have been made to divide the general field of vision, and to assign to the divisions distinct sub-areas in the general cortical region concerned in visual perception. The investigations of histology seem clearly to indicate that in the higher animals, and especially in man, the optic nerve contains one system of fibres which crosses over to the opposite side (either in the optic chiasm or beyond), and one system which remains uncrossed. *The retina of each eye appears, then, in man's case, to be represented on the cortical surface of both hemispheres of the brain.* Pathological cases confirm this conclusion from histology.

The assumed state of the case is then described by one writer in the following terms: "If we imagine the visual areas of the two cerebral hemispheres to be united in the middle line, we may conceive each retina as projected in its normal position over the united area. It will then at once appear that the upper and lower parts of both retinas will fall upon the corresponding parts of the united area; that the outer part of the left retina and the inner part of the right will fall on the outer portion of the left side of the united area, and *vice versa;* and that a vertical line bisecting each retina will fall along the line of union of the two cerebral areas."

Cortical Centres of Smell and Taste.—Nothing definite has yet been determined as to those areas of the human brain which are connected with sensations and perceptions of smell and taste. Both centres are located by Dr. Ferrier close together in the *subiculum* (see Fig. 68) and neighboring parts of the convolutions of the temporal lobe. Munk, however, would localize smell in the *gyrus hippocampi.* A recent writer (Dr. Mills), while admitting that the localization of the cortical centre of smell is still uncertain, thinks that the evidence points toward the region of the *uncinate convolution* and its vicinity.

The Centre of Hearing.—The upper convolution in the temporal lobe has been assigned by Dr. Ferrier to the auditory sensations. But this auditory centre is localized by Munk in the region marked *B*1 (see Fig., p. 199), for its greatest intensity; and with less intensity in the adjacent regions marked *B*. Recent investigations seem to indicate that the upper temporal convolution can be completely extirpated without disturbing permanently the sense of hearing. With considerable probability does one authority extend the so-called "auditory sphere" over the whole surface of the temporal lobe, and probably also the "horn of Ammon."

Centres Concerned in Articulate Speech. — To speak of a cortical centre for human speech seems in itself to involve an absurdity. All the processes of the mind are deeply and complexly involved in the use of language; if, then, we are to be faithful to the theory of localization itself, we are compelled to admit that a considerable part of the entire brain, including a variety of centres so-called, must exercise their functions in connection with these mental processes.

In treatises of the years 1861–1865, Broca announced the discovery that the lower convolution of the frontal lobe is "the seat of the faculty of articulate language." This way of stating the case involves the absurdity to which reference has just been made. But the discovery in physiology thus announced was of the highest importance and, properly stated, has maintained its place among the truths of cerebral science.

Phenomena of Aphasia. — Any permanent disturbance or loss of the power to apprehend, or to express one's self in, articulate language, if it is due to lesions of the cerebral cortex, is called "aphasia." The phenomena of this disease are exceedingly varied, and very interesting. They range all the way from those resembling the results of inattention in normal persons (*e.g.* such as that of the German professor who certified in writing, "A. B. has attended my remarkable lectures in chemistry with inorganic assiduity.") to the utter loss of intelligent speech, in cases of progressive paralysis with dementia.

Sometimes the aphasic patient is entirely speechless, but understands what is said to him, and can express himself in writing. Sometimes he can pronounce words of one syllable only; sometimes only a few senseless or extraordinary syllables or words. Not infrequently the ability to render certain words or sounds is joined with the inability to render other closely similar words or sounds, in a most surprising way. One patient, thus afflicted, could say "Bon jour," but could not say "bonbon." In another celebrated case the entire vocabulary of the aphasic person was limited to the five words, oui, non, tois (for trois), toujours, and Le Lo (instead of Le Long, the man's name). Four of these words were used with a substantially correct meaning; but "toujours" was the word employed whenever the patient could not express his meaning by gestures or by the rest of his stock of words.

Kinds of Aphasia. — The variety of phenomena connected with this form of cerebral disease is such as to provoke investigators to a more careful classification of the cases. Thus various subdivisions have been made. The word *agraphia* has been employed for the inability to express thought in written language, — an inability which may be incomplete or absolute. In some cases, highly cultivated persons become unable to produce a single letter with the pen. Others write long rows of letters arranged in meaningless fashion, or with a genuine word occurring here and there.

In certain cases of aphasia it is "word-deafness" which is the prominent factor in the disease. Persons thus afflicted hear words as confused murmurings, with no *meaning* in them; at the same time the sense of hearing for the tick of a watch may be very acute. In other cases, the patient can hear and articulate, but the "acoustic image" of the word as a symbol of the idea has perished.

In many cases of aphasia the phenomenon of what is called "word-blindness" is the most prominent factor. The connection of this disease with disturbances of the visual centres has been noticed by many observers. Some have held that "optical aphasia" is a distinct kind. Of seven reported cases of cerebral defect of vision, five of which had "psychical blindness" and could not read, six cases showed extensive lesions, generally in the occipital and temporo-occipital regions. Hence we may argue that the sight-centres in the occipital lobes are connected by association-fibres with the centres for uttering language in the temporal and frontal lobes.

Novel affections have also been noticed in which the patients can read a few lines, but apparently get no sense from it, and give up the attempt in despair. The name of "dyslexia" has been given to such cases; and in some of them *post-mortem* examination has shown lesions interfering with the tracts between the visual areas and the convolution in which Broca located articulate speech.

Dr. Starr suggests a name ("apraxia") for a wider class of cases, of which "word-deafness" and "word-blindness" are the best known examples. The significant feature of such cases is the inability to recognize the use or import of an object. Of this inability there may be as many kinds as there are kinds of sensations. The cerebral disease consists in the lesion of the connections which are normally maintained among the "residua" of the various groups of sense-impressions.

Cerebral Areas of Lesion in Aphasia. — In Exner's collection of cases, all but one of the 31 lesions resulting in aphasia were on the *left* hemisphere of the brain. Dr. Seguin, out of 260 cases, calculated the proportion of aphasias due to lesion on the left side as compared with the right, to be as 243:17 or 14.3:1. It appears then that, so far at least as the motor functions are concerned, speech is *left-brained.* In this (the left) hemisphere, the anterior central convolution and the adjacent convolutions of the frontal lobe, but especially the *back part of the lower frontal* convolution, have much the highest intensity as seats of aphasic lesions. Of 53 cases carefully collected by one authority, 50 were in the left hemisphere, 24 in the lower frontal convolution, 34 in this convolution and adjacent parts, 19 either in the Island of Reil alone or in it and adjacent parts. Yet the same authority gives 2 cases of aphasia following lesions in the front part of the frontal lobe, 3 in the parietal, 4 in the occipital.

Further Distinctions in Areas of Speech. — Attempts have been made, with more or less of probability, to localize the lesions which occasion the different kinds, or are connected with the different factors and phases, of aphasia. Thus Exner is inclined to assign "motor aphasia" to the third frontal convolution, "word-deafness" to the middle temporal convolution, and "agraphia" to the lower and front part of the parietal lobe. In partial but substantial agreement with him, another authority would locate "hearing language" in the first and part of the middle temporal convolutions; "seeing words" in the lower parietal; "writing" at the foot of the left middle frontal; and "speaking words" at the foot of the left lower frontal convolution. Each centre is thus situated amidst larger related areas, — the motor, in the wider field of arm, tongue, and jaw; and the sensory, in the general fields of hearing and sight. Each centre is, therefore, *the focus of certain kinds of memory-images.*

The foregoing delineations are rather more definite than it is wise at present to attempt to be. We cannot do better than to close this branch of the discussion with the remark of Kussmaul, "It is, *a priori*, probable that an enormous association tract in the cortex has been assigned to speech, even though the key-board of sound may be confined to the anterior cortical regions." With reference to the last clause, however, it is to be noticed that the loss of power to sing and to understand melodies, or to use and understand numbers, is not necessarily connected with the loss of articulate speech.

Evidence from Histology and Anatomy. — The general distribution of motor and sensory areas which has been made above is confirmed — or at least it is not disturbed — by researches in comparative histology and anatomy. That the motor tracts from below run to the frontal and front parietal and temporal regions of the brain, while the sensory lie, on the whole, in the direction toward the hinder cerebral parts, can scarcely be doubted (compare p. 72 f.). It is perhaps more doubtful, and yet, on the whole, probable — as says Dr. Starr — that "the third set of fibres of the projection system includes those which lie just posterior to the motor tract, and fill up to a considerable extent the space between it and the radiation of the visual tract, towards the occipital lobe." This set of fibres, he thinks, convey the sensory impulses of touch, pain, temperature, and the muscular sense. They lie around, and to a certain extent coincide with, and interpenetrate, the motor areas.

RELATION OF THE CEREBRAL AREAS TO "GENERAL INTELLIGENCE."

The more ardent advocates of the theory of the localization of cerebral functions find it difficult to refrain from assigning some portion of the cerebral cortex to the formation of concepts, and to the mental activities sometime spoken of as "general intelligence." Of course, for thi purpose the frontal regions offer themselves as peculiarl tempting. General considerations of comparative anatom might be said to favor this view. For it is with respect to the development of these regions, as one most significant feature, that the human brain surpasses that of all the other animals. Experimental evidence might also be appealed to,—such as that which finds the mentality of birds, for example, whose fore-brains have been removed without injury to remaining portions, reduced to a condition resembling idiocy.

On the other hand, there are perhaps no other portions of the human brain where so extensive lesions may occur with little or no impairment of any bodily or mental functions, as the frontal regions. Small lesions in other regions are not infrequently productive of much more serious mental disturbance.

It should also be noticed that the words "general intelligence" are somewhat ambiguous, and may be really misleading. Strictly speaking, there is no such thing as *general* intelligence. Especially in the earlier stages of development, and with the lower animals, any impairment of the sensory or motor functions occasions a certain disturbance or loss of "intelligence." In a case like that of aphasia, in man, how shall we separate between the definite and concrete loss of functions which we designate by "psychical deafness," or "psychical blindness," and the disturbance and loss of general mental power? *All intelligence is intelligence about something or other, and resting upon a basis of sensations and volitions.*

Moreover, the phenomena to which the veteran opponent (Goltz) of the theory of localization constantly appeals, show that, in the lower animals, the descent toward idiocy is, in a general way, proportioned to the amount of cerebral substance which has been functionally disturbed or extirpated. Even temporary functional impairment of the cerebral centres tends to pull any one down toward idiocy. Such impairment occasions a diminution of mental vigor which shows itself in more or less specific ways, according to circumstances. Goltz describes a dog which lived for fifteen months after having lost one entire hemisphere, basal ganglia included. Both motion and sensibility were impaired on the side opposite the lesion; but there was complete loss of no sensory or motor function. The animal was a simpleton, without fear or sportiveness, and with impaired hearing and sight. But the removal of one frontal lobe from an animal is found to occasion little or no severe disturbance of mental functions. With both frontal lobes gone, however, the animal cannot eat unaided, nor use his paws as hands. The removal of the occipital lobes occasions, Goltz believes, far more profound changes than loss of both eyes; the animal then loses psychical fear and interest, and is mentally degenerate.

In man's case we can localize with considerable success the functions on which the psychical quality of sensory impressions is dependent; and we can point out the tracts which must be traversed if memory-images are to be aroused, and the impressions attain a meaning and connection with the past mental life. But as to cortical areas which may serve as a physical basis for the mental activities that are "logical" or "intellectual,"—in the higher sense of these words,—we are quite in the dark as to where to look for them, or as to the use to which we should put them in case they could be found.

Summary of Principles. — Three principles seem to sum up the results obtained by discussion of the evidence adduced in the two preceding chapters.

1. *The Principle of Use and the Law of Habit.* The different elementary parts of the nervous system become capable of performing their specific functions, only when brought into proper connections and exercised in the performance of those functions. No elements or groups of

elements act in isolation; what they do, and can do, depends upon their connection with other elements. This is especially true of the different minuter or larger areas of the cerebral cortex. Their functions are dependent upon their relations to one another and to the inferior regions of the brain, as joined together by "association-fibres" and "projection-fibres."

Moreover, the repeated action of the nervous elements, in the connections in which they are placed, develops in them a special fitness for performing specific functions. The areas of the cortex improve by exercise. By repeated activity, in their appropriate connections, they gain in facility and value with respect to their specific functions.

2. *The Principle of a Local Specialization of Function.* In the cerebral cortex, as elsewhere through the entire nervous system, certain parts have, in all normal and ordinary circumstances, certain specific functions to perform. In the spinal cord we found particular areas, either as located by a cross-section at each altitude, or as so-called "centres" placed above and below each other in the length of the cord, to have specific functions assigned to them. In the lower parts of the brain the principle of the localization of function appears to be also carried out. The evidence adduced in the last two chapters establishes beyond reasonable doubt the existence of the same principle as applied to different parts of the cortex of man's brain. And, indeed, it is just here that we should expect to find the most definite and perfect application of the principle.

So-called "centres," or "areas," or "fields," of the surface of man's brain are in no case, however, to be regarded as portions of its nervous substance that mark the limits within which specific functions are always rigidly confined. Such "centres" are not to be thought of as mathematical points or as definitely circumscribed collections of cells. They do not appear to be perfectly isolated localities. They are not necessarily the same in their exact outlines for individuals of the same species, or for the same individual at all times. They widen when a heightened energy is demanded of them. They obviously overlap and interpenetrate in certain cases. Especially is this true of the regions in which the motor and sensory functions are connected for the control of the same parts of the body. They are intimately interconnected and associated in function; so that one of them cannot, as a rule, be cut out without injury to others; or its function greatly impaired without disturbing the function of other associated centres.

3. *The Principle of Substitution.* Furthermore, the performance of the functions allotted, as it were, to these so-called centres, is not necessarily, under all circumstances, confined to them. If such areas become absolutely or relatively unfitted to perform their normal functions, it is possible, within certain limitations, for other areas to *assume* these functions. The areas, however, which can be substituted must have the proper connections. It is due, in large part, to the working of this principle of substitution, that animals subjected to experiments in extirpation, as a rule, recover the powers of sensation and motion which they have temporarily lost. A certain large elasticity, as it were, of the nervous system is implied in the very laws of reflex or sensory-motor activity as applied to the spinal cord (see p. 139 f.). This principle does not operate arbitrarily; it will not meet all possible demands made upon it.

The portions of the same hemisphere of the brain that are just adjacent to the so-called "centres" (the larger areas surrounding or continuous to the smaller), and, on account of its bilateral structure, the corresponding portions of the other hemisphere, are best capable of exercising their substitutive functions. The assumed functions also fall, of course, under the law of habit. Perhaps these statements cover all that it will finally be found necessary to admit.

CHAPTER X.

THE QUALITY OF SENSATIONS.

THE variety of our sensations seems, on first reflection, bewilderingly great. But the popular way of viewing them has reduced them all to five classes, according to the organs of the body through which the sensations are known to be received. Hence the five kinds of senses — smell, taste, hearing, sight, and touch — which everybody recognizes. The inadequacy and, in some respects, inaccuracy of this popular classification are readily made apparent. But it is not seen, without careful and detailed scientific research, what classification ought to take its place. The various and uncertain uses of the word "*feeling*" are calculated to emphasize our doubts and difficulties on this point.

Simple Sensations. — Strictly speaking, there are no experiences of which we are conscious that can be called *simple* — or absolutely uncompounded — sensations. Indeed, in all our adult life we have no experience even of pure but complex sensations, as such, — that is, of sensations regarded as states of consciousness disconnected from images of memory and imagination, and unrelated to things, perceived or imagined, as their so-called "qualities." Moreover, the simplest sensation which we can detect in connection with our perceptions or memories of things is no more absolutely simple to psychology, in its nature, than is the drop of water to chemistry.

The "simple sensation" is then a fiction of psycho-physical science. It is not realizable as a state of consciousness in experience. It is a theoretical factor into which science breaks up those complexes of consciousness which have the predominating characteristics of all sense-experience.

Quality distinguished from Quantity. — Consciousness enables us to distinguish between the quality and the quantity, or intensity, of our sensations. We are immediately aware both of *the kind* of the mental affection which arises through excitation of the organs of sense, and also of variations in its *amount.* Thus a distinction is possible between "the how" and the "how much" of the resulting state. That the quality and the quantity of sensations are closely related, our experience makes perfectly clear. Intense smells and tastes are different from weak ones, in their characteristic quality, even when they are excited by the same object. Very intense sensations of every kind tend to pass over into sensations of pain. Sensations of light touch differ in kind from those produced by heavier pressure of the same object on the same locality of the organ. Yet the distinction between quality and quantity is clearly made by the consciousness of every one.

Questions relating to the Determination of Quality. — The inquiries which physiological psychology raises concerning the quality of sensation are, chiefly, these four: (1) What is the precise locality of the organism where the specific excitation which occasions each kind of sensation originates? (2) What is the character of the stimulus, and the nature of its action upon the organism, in producing the specific excitation? (3) What are the various kinds of sensations which appear in consciousness and the various corresponding kinds of stimuli on which the sensations are dependent? (4) What are the laws by which the quality of the sensations is related to the several kinds of stimuli? None of these questions can be answered completely by modern experimental psychology. But something of a strictly scientific character can be said in reply to each; and none of them can be properly neglected in our considerations. We shall not, however, think it necessary always to keep their consideration separate.

SENSATIONS OF SMELL AND TASTE QUALITATIVELY CONSIDERED.

In beginning with these sensations we are considering those, first, which are least intellectual in quality, and at the same time most indefinite and difficult to reduce to terms of scientific statement.

Excitable Region for Sensations of Smell.—It has already been shown (p. 74 f.) that the part of the mucous membrane of the nasal passages known as the *regio olfactoria* contains the end-organs of smell. Here the nerve of smell (*olfactorius*) is spread out. It must be reached by the stimulus being, in all ordinary circumstances at least, borne thither by the current of air in the act (usually, if not always) of inspiration.

Stimulus of Sensations of Smell.—The excitation of the end-organs of this sense seems to require that the stimulus should act upon them in gaseous form. Thus objects like arsenic, which at ordinary temperatures are inodorous, when vaporized by heat, excite intense sensations of smell. Fluid bodies which give off an odorous reek, when brought in their fluid form into contact with the organs, as a rule, have no smell. Most observers have followed the opinion of Weber, who held that no fluid, not even eau de cologne, when poured into the nostrils and remaining against the organs, can excite olfactory sensations. The reason for this has been attributed to the temporary impairment of the organs by being soaked, or to the mechanical barrier which the fluid makes between the odorous particles and the apparatus of smell.

The conclusion of Weber has more recently been contested. It has been considered that fish have true sensations of smell. And some observers report that, by using a ⊥ tube and introducing into the nostrils solutions of camphor, clove oil, cologne, etc., they have succeeded in exciting the specific smells of these substances.

Mechanical and Electrical Excitation of Smell. — Some physiologists have asserted that they could obtain sensations of smell by different forms of mechanical irritation, such as vibration of the nostrils, violent sneezing, etc. Nearly a century ago Ritter experimented by using bits of graphite and zinc thrust into the nostrils, and thought he thus excited genuine sensations of smell. He described the positive pole as effecting a trace of smell like that of "ammonia"; the negative pole produced a kind of "sour" smell. It is by no means certain that these sensations were not sensations of touch and taste rather than specific sensations of smell. And although some modern experimenters claim to have a distinct sense of smell, for example, with the cathode in the nose on opening the current, and with the anode on making the current, the electrical stimulation of specific sensations of this sense can scarcely be said to be experimentally established. There is no proof that thermic stimulation will excite the sense of smell.

Subjective Sensations of Smell. — Experiments to prove that the sense of smell may be excited in animals by injecting odorous substances into their veins are very uncertain. Human pathological cases show that compression of the olfactory nerve by tumors may produce sensations. There is no doubt that disturbances of the central organs, such as accompany insanity, may cause subjective smells. Indeed, to be thus afflicted is sometimes symptomatic of disease of the brain. And we know how powerfully the brains of some persons are affected, so that nausea and giddiness result, by even very weak odors from some substances.

Properties of Odorous Bodies. — There seems to be no one characteristic which a body must possess in order to excite the specific kind of sensation which we distinguish as that of smell. Some plants are odorous by day alone, others by night alone. Some have a smell when dry; others give off only a weak odor when dry, but a stronger one when moistened. In general, the effect of any odorous substance depends upon the ease with which it may be vaporized, and the speed and extent of its diffusion through the atmosphere.

In 1756 it was discovered (by Romieu) that small bits of camphor on water exhibit a peculiar rotary motion. It was afterwards shown that other odorous bodies have a similar motion on the surface of water; and that a thin layer of water on a perfectly clean plate will withdraw itself as soon as pulverized camphor is spread upon it. Similar phenomena have been noticed in the cases of some two hundred odorous substances of either vegetable or animal structure. From such data the conclusion is drawn that all odorous substances have the power, especially when in contact with moisture, to set up such a motion of their outside particles as distributes them through the surrounding atmosphere. Beyond the general theory, that the power to give off those peculiar "effluvia" which excite the end-organs of the olfactory nerve is characteristic of all odorous bodies, it cannot be said that much is known.

Classification of Smells. — The specific sensation of smell must, first of all, be distinguished from other forms of sensation with which it is combined and ordinarily confounded. Many so-called sensations of taste (as that of the onion, etc.) are really sensations of smell. Substances like ammonia and acetic acid excite sensations of so-called "common feeling" through their action on the *trigeminus* as well as the olfactory nerve.

But after these distinctions are carefully made, all attempts to classify sensations of smell, *as such*, remain unavailing. The division into pleasant and unpleasant depends upon the changing whims of individuals. To some persons the smell of assafœtida, of burning feathers, of rank cheese, is pleasant. A classification according to the objects which yield the odor ("smell of a rose," etc.) is not a classification of sensations of smell at all. A classification on chemical grounds is unsatisfactory; chemists differ much concerning the smell of the same substances. Nor have the attempts to distinguish various olfactory fibres, or systems of fibres, as appropriated to specific sensations, been successful.

We are obliged then to say that no known principle will bring order out of this bewildering confusion. There is no classification of the sensations of smell, as such. To quote from a prominent authority: Sensations of smell form "a discrete manifoldness which has an unknown arrangement."

Our knowledge respecting *Sensations of Taste* and their excitement and laws is only a little more advanced than that respecting sensations of smell.

Excitable Regions for Sensations of Taste. — The question whether a tastable substance excites specifically the same sensations, when applied to all places of the organ of taste, is somewhat difficult to answer experimentally. Descriptions which speak of tastes as "prickly," "piquant," "cooling," etc., confound other sensations with those of this sense. The more general conclusion seems to be, that sweet and sour are tasted chiefly with the tip of the tongue, bitter and alkaline with its roots. In 1888, in the laboratory of Johns Hopkins, it was discovered that a certain derivative of saccharine would produce sensations of bitter when applied to the back part of the tongue, and of sweet when applied to the tip and borders of the anterior half. It should be said, however, that another observer reports the sensibility of the *root* of the tongue for sweet greatest in nine cases out of ten, with which he experimented, and of the *edges* of the tongue for sour, in seven cases out of ten. The same observer, however, found that the root retains best its taste for bitter, and worst its taste for sour.

In all such experiments considerable allowance must be made for the idiosyncrasies of individuals. It must also be remembered that it is difficult carefully to circumscribe the application of stimulus to the end-organs of taste. Moreover, in some cases the sensibility to excitement extends outside of the tongue more widely than is common; it may be found in the soft palate and the contiguous arch. Indeed, the record of one patient is given who, when the entire tongue had been removed, retained some taste caused by touching the back of the throat or the mucous membrane of the stump.

Stimulus of Sensations of Taste. — Only fluid bodies, or such as are soluble in a fluid or menstruum, excite sensations of taste. Absolutely insoluble bodies are, without exception, tasteless. Not all soluble substances, however, excite sensations of taste; and no known law regulates the relation between the two. It has been claimed by some experimenters that certain gases, when made to act upon the organs of taste, excite in them the specific sensations of this sense. It is difficult, however, to prove that the tongue has been so thoroughly dried in any case, as to prevent the absorption of these gases by its moist capillary layer.

Mechanical and Electrical Excitation of Taste. — It is doubtful whether the sensation of taste can be excited by mechanical means. Certain authorities of high rank describe such sensations as mingled with the feelings that follow rubbing or pressing the tongue. The debate over the question whether electrical stimulation excites sensations of this sense continued for a hundred years. It was finally shown that, when a chain of four persons is arranged in such a manner as to send a current of electricity through the tongue of one, the eyeball of another, and the muscles of a frog-preparation, held by two of the four, the same excitation causes, simultaneously, an acid taste in the mouth of one observer, a flash of light in the eye of another observer, and a movement of the muscles of the frog. Other experiments confirm the view that electricity *is* an excitant of the sensations of taste.

Subjective Sensations of Taste. — The attempts made to prove that animals may be affected with sensations of this sense by injecting tastable substances into their blood, have led to no result. Most of the alleged instances of subjective sensations of taste are probably due to substances really brought to the tongue in the saliva. It is noteworthy that we rarely or never dream in terms of this sense.

Properties of Tastable Substances. — As to what it is in certain substances which fits them to excite the end-organs of the tongue and soft palate, we are much in the dark. Experiments lie in the line of discovering some relation between the chemical constitution and action of these substances and the different kinds of taste. This relation has been thought to be of the simplest sort with the acids; a great variety of which, when we exclude the sense of smell, are found to have the same taste. Many of the *carbon compounds* have a distinct *sour taste.* Moreover, all the *soluble chlorides* are found to be *salt* (like table salt); only with the highest members in the series of compounds the taste becomes more saline and develops into a bitter. Many *sweet substances* are *alcoholic bodies*, and contain the radical CH_2OH.

On data such as the foregoing it has been claimed[1] that tastable bodies are surrounded by vibrating matter which acts on the sensitive surfaces of the organ; and that the quality of the sensation is dependent upon the character of the vibrating matter. Just as a certain class of salts of allied physical and chemical properties vibrate in a certain way, and stimulating the eye, produce the same color-sensations; just so do similar sapid compounds, which contain elements of the same compound radical, vibrate in similar way and produce the same taste. Apparent exceptions to the simpler laws may be due to the fact that the tongue, like the eye, has no power of analysis. The same taste may then be produced by a simple vibration, or by a compound of simple vibrations.

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[1] For example, by J. B. Haycraft, in Brain, July, 1887.

Classification of Tastes. — Sensations of this sense are, in ordinary experience, combined with those of smell, touch, temperature, common feeling, and the muscular sense. It has been customary to distinguish at least four specifically different sensations of taste, — namely, sour, sweet, salt, and bitter. To them Wundt would add the alkaline and the metallic. All other so-called tastes are then supposed to be compounds of these specific, simple sensations of taste with one another, and with the other kinds of sensations mentioned above. It seems very doubtful, however, whether this classification will satisfy all the experiences we have under this sensation. In consciousness, the sensations of this sense, like those of color and light, are not analyzable into so few simple elements. The *sensations*, as such — that is to say — are not exhaustively classified. Moreover, the similarity of our sensations of taste to those of smell, in respect of their bewildering variety, is quite too marked to make us satisfied with any of the existing schemes of classification.

SENSATIONS OF THE SKIN, MUSCLES, JOINTS, ETC., QUALITATIVELY CONSIDERED.

At least two specifically different sensations — namely, Pressure and Temperature — have generally been admitted to have their organ in the skin. It is only recently, however, that the sensations arising by irritation of this organ have been discriminated and discussed, in a thorough manner, by experimental means of investigation. In general, it should be said that many of the sensations which we localize in the skin are really of cerebral origin, and result from the compounding of a variety of sensory impulses, in the appropriate way, within the cerebral centres.

Excitable Regions for Sensations of Pressure. — The so-called "feelings," or more properly *sensations of pressure*, are dependent upon the excitation of the sensory nerves of the skin through their end-organs. The excitation of the trunk of these nerves produces sensations of pain, but not those definite sensations of touching and being touched, which we are able so definitely to localize.

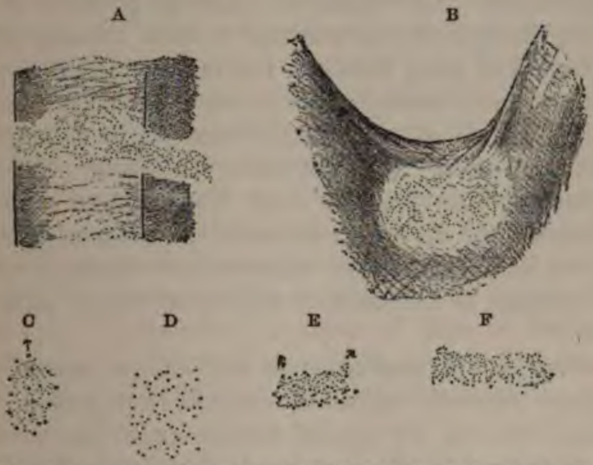

Fig. 73. — Arrangement of Pressure-spots (Goldscheider). A, dorsal and radial surface of the first phalanx of the index finger; B, membrane between thumb and index finger; C, dorsal surface of fore-arm; D, back; E, inner surface of fore-arm; F, back of hand.

It is a comparatively recent discovery that the definite pressure-sensations are aroused only by exciting minute areas of the skin called "pressure-spots." These spots are arranged in a manner somewhat like that of the "temperature-spots" (to be explained subsequently). They are placed in chains, as it were, sometimes more and sometimes less thickly set. These chains ordinarily radiate from a kind of central point, and run so as to form circular, or pyramidal, or longitudinal figures. They are most numerous in the areas of the skin most sensitive to pressure. The different spots differ in regard to sensitiveness; some are much more easily excited than others.

Distinctions in Pressure-sensations. — The investigations of Goldscheider lead him to distinguish two specifically different sensations which enter into what is ordinarily called the "feeling of pressure." If a very fine point of metal, wood, or cork, be touched lightly to the skin, it will be found to awaken a definite sensation only at certain minute spots. This sensation, when the pressure is light, is very lively and delicate, and is often accompanied by the feeling of being tickled. On increasing the pressure, however, the sensations change their character; the feeling becomes as though a small hard kernel were pressed against the skin. Between these spots it is not possible by pressure to excite the same characteristic sensations. Stimulation of the spaces between the pressure-spots produces a dull, indefinable, "contentless" sensation; and, if the pressure is increased, a feeling of being pricked or stuck.

In respect to quality, pure and simple, sensations of pressure scarcely admit of further classification. We localize them in the general field of touch; but we do not recognize kinds of them, as we do in the case of sensations of smell and taste. The distinction between "light touch" and "sensations of weight" is one of degrees of compound sensations involving the muscles and joints, etc., as well as the skin. As simple sensations, they differ in intensity rather than in quality strictly so-called.

The attempt has sometimes been made to identify sensations of light touch with sensations of temperature. Weber held that cold bodies resting on the skin appear heavier than they are, and warm bodies lighter. One silver dollar of the temperature of 25°–19½° F. appeared as heavy as two dollars of 98½°–100½°. The same conclusion has been drawn from the observation that it is difficult to distinguish, in certain parts of the skin when irritated through a square opening in a piece of paper, whether the cause of the irritation is a light brush from cotton or the approach of a slightly heated surface. But small wooden disks, when heated to 122° F., were found by another observer to feel heavier than really larger ones when not warmed. And even if the same stimuli could be used to excite either one of these two classes of sensations, the qualitative distinctness of the sensations themselves would not be impaired. Moreover, cases have been reported where areas of the skin suffering from a complete loss of sensitiveness to light pressure have been more highly sensitive than was normal to sensations of temperature.

Excitable Regions for Temperature-sensations. — Certain minute areas, and these only, are susceptible to irritations of a kind to result in sensations of heat and cold. Such spots are insensible to pain and probably also to pressure. Moreover, some of these minute areas are sensitive to cold only ("cold-spots"); others of them to heat only ("heat-spots"). When the topography of the skin is carefully mapped out, these two kinds of temperature-spots appear not to be superimposed. They are not located alike on the symmetrical parts of the two sides of the same individual, nor on the corresponding parts of different individuals. In general, they occur in lines that radiate from centres coincident with the roots of the hairs. These lines often cross each other and form figures of various shapes. Heat-spots are, on the whole, less numerous than cold-spots; but in parts of the body where the skin is most sensitive to either temperature, the corresponding kind of spots is most numerous. "Temperature-spots" have been divided into first class and second class, according to the degree of strength with which they react on moderate stimulation. Some of them are irritated only by excessive temperatures. The same temperature may seem ice-cold to one spot and only cool to another.

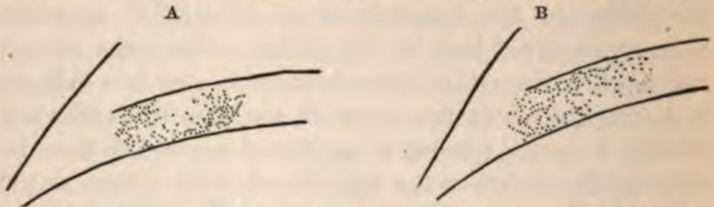

FIG. 74.— Arrangement of Temperature-spots. A, heat-spots; and B, cold-spots— from the palm of the left hand (Goldscheider).

Stimulus of Temperature-sensations. — Whatever form of energy excites the nerves of the skin at the "heat-spots" or "cold-spots" calls forth the specific sensations corresponding to these spots. Thus, the electrical current, or puncturing the skin with a point, may be felt as either cold or hot, respectively. Among the inducements to sensations of heat, the following have been mentioned by Hering as the more ordinary: All checking of the radiation of heat when the blood-supply remains unaltered; all contact with a medium or an object of higher temperature; all increase to the heat of the skin coming from the interior of the body. On the contrary, different areas of the skin feel cold, when the convection of the heat from the skin increases while the blood-supply remains unchanged; when there is contact with objects that have the same temperature as the air, but convey the heat more rapidly than it; on contact or proximity to objects colder than the skin; and on lessening, in any way, the interior warmth of the body.

Laws of Excitation for Temperature-sensations. — It is difficult to bring the recent discoveries in physiological psychology, regarding the origin and nature of temperature-sensations, into any relation with the physics of objective heat as a mode of motion. It will be seen (when we come to consider the perceptions that arise through these sensations in part) that psycho-physical principles — such as those of contrast, relativity, exhaustion, etc. — have a large share in determining the character of this class of our particular experiences.

Sensations of temperature seem also to have a certain dependence on the temperature of the thermic apparatus itself. This law has thus been stated by its leading exponent: "As often as the thermic apparatus at any point in the skin has a temperature which lies above its own zero-point we have a sensation of heat; in the contrary case, a sensation of cold. Either sensation is so much the more marked or stronger, the more the temperature of the thermic apparatus at the time varies from the temperature of its own zero-point." [By the "zero-point" of any part of the skin is meant the exact objective temperature which at that part will produce *no* sensation of either heat or cold.] According to this principle it is proposed to explain all our ordinary sensations of temperature.

The earliest great observer in this field (E. H. Weber) thought, however, that all rising of the temperature of the skin is felt as heat, and its sinking as cold. Thus, if we hold one hand in moderately cold water, and dip the other repeatedly in the same water, the sensation of cold is stronger in the latter, although the temperature of the hand held constantly in the water is the lower. Yet the most important recent observer (Goldscheider) calls attention to an experiment which shows that, if one hand be left for ten seconds in water of the temperature of 104° F., and then both hands immersed in cold water, the warmed hand will feel the cold less distinctly than the other.

Our perception of the absolute degree of temperature, and of minute variations in temperature, is most acute for places in the scale lying close to the normal temperature of the skin. It must be confessed that the exact manner in which changes of objective temperature act upon the thermic apparatus to excite it is unknown. Possibly the immediate stimulus of this apparatus consists of some form of chemical or electrical energy developed by the increase and decrease of that molecular motion which physics calls "heat."

The question whether qualitatively distinct sensations arise in the mind through irritation of sensory nerves seated in the muscular fibre has been much debated. In our judgment, however, valid reasons may be given for maintaining the existence of *Muscular Sensations.* Most of the evidence in proof of this position properly belongs in connection with the development of complex perceptions of the position and movement of the eye, the limbs, etc.

Existence of Sensations of the Muscular Sense. — For some time it was disputed whether the muscular fibres are directly connected with sensory nerve-fibrils. In 1874 Sachs apparently demonstrated the affirmative of this disputed question. The psychological evidence for muscular sensations is partly immediate, and based upon the testimony of consciousness, and partly indirect and experimental.

It can scarcely be doubted that we localize certain massive sensation-complexes in the muscles of the different parts of the body. This impression is peculiarly fresh and strong when, attending carefully to our sensations, we lift weights, or take positions, which call into action unused muscles of the limbs or trunk. In itself considered, little stress might be laid upon this appeal to the immediate testimony of consciousness on a psycho-physical question. But it will become apparent by our subsequent study of perception that the theoretical need of muscular sensations, in order to account for the knowledge of the developed mind, confirms the testimony of consciousness.

Moreover, experiment and observation of the more careful scientific sort, on the whole, favor the assumption of a muscular sense, whose sensations vary in the quality which they assume in the conscious life of the mind. For instance, there seems to be no regular parallelism between the loss of the other modes of sensibility and the loss of muscular sense-impressions. In rare cases, in what is called "locomotor ataxy," there may be little loss of ordinary sensibility and yet a marked deprivation of muscular sense. On the other hand, sensibility of the skin may be impaired or destroyed without impairing the ability to discriminate weights when the muscles are moved.

A recent experimenter found that, after temporary destruction with cocaïn, of the sensibility of the larynx and vocal cords, a singer could sing almost (if not quite) as accurately, as respects pitch, as before. With what did this singer guide his voice, if not with the muscular sensations and their memory-images? Another observer reports the case of a patient who had lost an area of skin, 10×12 centimeters, without any influence on the muscular sensibility of the subjacent contractile bodies.

Nature and Kinds of Muscular Sensations. — The precise manner in which the muscular sensations are originated, by excitation of the sensory nerve-fibrils lying within the muscles, is unknown. The stimulus immediately acting on these end-organs might be conceived of as either mechanical or chemical, or electrical. It can scarcely consist in the mere irritation caused by the molecular changes that accompany the contraction, tension, and relaxation of the muscles. We do not see, however, that our ignorance of the manner in which degrees of pressure act to produce, through the end-apparatus of sense, different qualities of sensation, is much more profound in the case of the muscles than in the case of the skin.

It must also be confessed that muscular sensations are very difficult of analysis by the method of self-consciousness. In consciousness they exist as complexes, entangled with sensations that arise through irritation of the "pressure-spots" and "temperature-spots" of the skin, and in the joints, etc. Moreover, muscular sensations, of themselves, seem to differ chiefly in "extensity," and quantity, or intensity, rather than in quality. It is only as already localized, and combined with sensation-complexes of other kinds, that the muscular sensations admit of being distinguished as respects quality.

To this very difficult subject we shall return in other connections.

Sensations of the Joints, Tendons, etc. — Experimental evidence has tended to show that certain kinds of sensations, of value in our perceptions of the positions and motions of the body, originate in the joints. Goldscheider experimented by resting the hand, palm upward, in a plaster cast, bending the index finger back by changing the pressure of a small weight, and then measuring the least angle of bending which could be perceived at the first joint. By a faradic current complete insensibility of the joint was then produced. It was now found that the finger must be bent farther than before in order to have its flexure perceived. Sensations produced by irritating the nerves of the joint would appear, then, to enter into the perception of the movements of the finger. It has also been discovered that ataxic persons can recognize slow movements of the limbs with short excursions, if accompanied by pressure on the joints; otherwise not.

Various Unclassified Sensations. — Experiments with a travelling metallic point, carrying the stimulus of a current of electricity over the skin, reveal an astonishing diversity of sensations awakened at different points of the surface. "Thrill-points," "tickle-points," and points of cutting pain, are all thus distinguished through irritation of the same stimulus. Places occur where the rate of motion seems suddenly to increase without any objective increase of its rate ("acceleration-points"); other places occur where, although continuing to move with uniform velocity, the travelling point seems to stop ("blind-spots" of the skin). Strange *tangles* of sensation, from which unaccustomed sensations can be partially disentangled, spring up in consciousness.

"Sensations of motion" are sometimes spoken of as though they formed a distinct kind. This we believe to be incorrect. Without a succession of qualitatively different sensation-complexes arising in consciousness, no perception of motion can occur. This perception is, however, peculiarly fundamental and instinctive, as it were.

THE QUALITY OF SENSATIONS OF SOUND.

There are two kinds of sounds — *tones*, or musical sounds, and *noises*. The latter are those sounds which are wanting in periodic regularity of stimulation and in the peculiar, pleasant modification of consciousness which tones have. Tones and noises are actually blended in nearly or quite all sounds. Noises may be compounded out of musical sounds, as, for example, by striking at once all the notes of an octave upon a piano-forte. Noises are not easily classifiable and are of little interest either to physical or to psychological science. Hensen has, however, distinguished three "categories of unmixed noises"; these are the "beats" (or pulsations which disturb the purity of some musical tone), the crackle, crack or crash, and the hissing noises.

Nature of the Musical "Clang." — The tones of ordinary experience are *complex* sensations. They result from the blending of several simple tones into one compound tone. This blending is not so complete, however, that a trained ear cannot analyze it. For the complex musical sounds of ordinary experience we borrow from the German usage the word "clang." The quality of tones considered as simple sensations is their *pitch*, which is spoken of as "high" or "low," according to the place which we assign to our acoustic sensations as immediately apprehended, and compared together, in consciousness. The quality of the complex tones, or "clangs," is the so-called *timbre*, or "tone-color."

The Pitch of Simple Tones. — It has been said that the quality of simple musical sounds is their "pitch." Subjectively considered, this quality is immediately determined by the place we assign the tone in a musical scale. In this scale — for reasons to which reference will subsequently be made — we fix all notes as higher or lower, on comparison of their characteristic quality. Objectively considered, the pitch of tones depends upon the rapidity of the periodic vibrations (the number in a given unit of time, usually one second) which occasions them, or, what is the same thing, it depends upon the length of the sound-waves.

The pitch of tones is theoretically determined by measuring the number of vibrations found necessary to produce some characteristic musical sound which it is convenient to select as a fixed point in the musical scale. The place of the other tones may then be fixed with relation to this tone selected as a point of starting, according to those simple numerical relations between the tones with which physics has made us familiar. Thus, in the German scale the tone of the pitch called a^1 is fixed at 440 vibrations in a second. The French scale fixes the same tone at 435 vibrations, and the theoretical pitch in England gives 512 vibrations for c^2.

Limits of Pitch. — Sensations of musical sound have both an upper and a lower limit; that is to say, vibrations either below or above a certain number per second produce no sensations of musical sound at all. The difficulties of determining these limits are great, and considerable allowance must be made for individual peculiarities. Some persons can discern tones of a pitch below or above those tones audible to others. Helmholtz thought that the *tone* (or musical quality) of the sound begins to fade out when the vibrations are fewer than 34 per second. Tuning-forks, vibrating 28 times in a second, have been heard as a weak drone. Preyer, however, considered that 16 vibrations enabled him to hear a tone. For most ears vibrations slower than 28 to 32 per second make only a buzzing or groaning noise.

The majority reach the upper limit of pitch when listening to tones produced by 20,000 to 22,000 per second. Some persons can, however, hear musical sounds produced by 30,000 or 40,000 vibrations in a unit of time. Perhaps in certain very sensitive ears the upper limit may be placed as high as 50,000. More acute tones than these are unpleasant noises, and finally become inaudible.

The range of the average human ear is rather more than nine octaves of pitch, — reaching from about A_2 of the subcontra octave (27½ vibrations, German scale) to above c^7 of the seven-times-marked octave (16,896).

Sensitiveness to Differences of Pitch. — Preyer found that unpractised persons, experimenting with the octaves lying in the middle of the musical scale (from c to c^2), distinguish a difference in pitch corresponding to from 8 to 16 vibrations per second. A few are, however, so "deaf" to pitch that an interval of less than a musical "third," or even, in the higher and lower parts of the scale, a "seventh," is indistinguishable. If a person is insensitive to differences of less than a tone or a semi-tone, he may be said "not to know one note from another." In a trained musical ear the sensitiveness may be much greater than that mentioned above. Thus, in the range most easily covered by the human voice (c^1 to c^3) successive notes can be distinguished, as respects pitch, when they differ by not more than $\frac{1}{3}$, or even $\frac{1}{4}$ and $\frac{1}{5}$, of a single vibration. Thus, where the piano gives 24 notes, the ear can perhaps distinguish 3000. But in the upper limits of the scale (*e.g.* above c^5) well-trained ears may identify notes that differ by 100, or even by 1000, vibrations per second.

Distinctions in Purity of Interval. — Individuals differ greatly in their ability to tell when two notes of different pitch have just the right amount of interval. This ability varies in all persons for different intervals. Thus, if the sensitiveness of the trained ear for the purity of the interval of an octave were denoted by 5000, that for the purity of the interval called "the fifth" would be 822; for "the fourth," 211; for the "major third," 198; for the "minor third," 117; etc.

Judgments of Absolute Tone. — We have already said that discernment of difference in the pitch of tones is immediate; and that an appeal to consciousness indicates the place to which each note, in comparison with other notes, shall be assigned in the musical scale. But discernment of the absolute pitch of a musical sound is a very complex and difficult operation, dependent upon natural "good ear" and upon training. One observer (Stumpf) found, by experimenting upon four persons, all musicians, that only one of them seemed even to approach infallibility.

Means for Discernment of Pitch. — The trained musician can put several hundred tones, distinguished in pitch by the ear, between the notes sounded by two white keys of a piano, at the most favorable parts of the scale. But Jenny Lind scarcely succeeded in singing in quarter-tones. It would seem then that the muscular sensations connected with forming or apprehending the quality of musical sounds do not furnish our sole means for discriminating differences of quality. This power seems to be an immediate comparison of the tones, as heard, in our consciousness.

Formation of the Scale of Pitch. — The arrangement of musical sounds in a series called a "scale" depends upon an immediate power of the mind to discern the difference in characteristic quality between any two notes when compared. This arrangement is conveniently symbolized by a series of different positions assigned along a straight line. Of any three unlike tones, one *must* be, and *only one* can be, arranged as respects pitch between the other two. Whenever any two tones, as, for example, m and n, are given, another "sliding" tone which begins with m and ends with n is possible. In this respect the scale of musical sound is — as we shall see — different from that of the varying shades of color. There are two ways of going from yellow to blue (*i.e.* through green and blue-green, or through violet, red, and orange); but there is only one way of getting from a^1 to c^3 (viz. through b^2, c^2, d^2, etc.). The series of tones is therefore spoken of as a continuous and infinite series.

The terms which we apply to the relations as respects quality, of the musical sounds in the scale — "high," "low," "intervals," etc. — are taken from the complex tactual, muscular, and visual sensations which accompany and fuse with the acoustic. In sounding the so-called "lower" tones, the vocal organs are depressed; in sounding the "higher," they are elevated. Low notes make in consciousness the impressions of breadth and gravity which correspond to the foundations of a spatial structure. In reading the musical scale by sight, we look *up* for notes of the higher pitch, *down* for those of the lower pitch. In playing on stringed instruments, the hands are correspondingly moved. Properly speaking, however, differences of pitch are not representable as relations of space. In other words, the terms applied to such differences all result from associated mental impressions.

The Timbre of "Clangs." — When any single note is sounded on a musical instrument, or by the voice, the result is a "clang," or composite musical sound. This clang may be objectively regarded as the summing-up of the waves of a fundamental tone (the simple tone of the note sounded) and the waves of certain partial tones belonging to the fundamental tone. The stimulus which occasions the complex sensation is, then, a complex sound-wave. The composite quality of each "clang" depends upon the character of this complex sound-wave.

We have seen that each sensation among the ordinary musical "tones" is composed in consciousness of several absolute qualities of simple tones. Every "clang" may be subjectively regarded as the fusion, more or less complete, in consciousness, of the simple and qualitatively unlike tones corresponding to the composite acoustic waves. These partial tones, or "over-tones," are the "harmonics" of the clang, or single compound tone. This composite quality or "coloring" of the note thus produced, and which is different for different instruments and voices, is called its "timbre." It is dependent upon the number, pitch, and relative strength of the simple tones which are compounded into the "clang."

Those simple tones, whose vibrations stand in simple mathematical relations when combined into a "clang," produce in consciousness a peculiar, pleasant sensation; those whose vibrations stand in complex mathematical relations, when combined, produce an unpleasant sensation. Thus the eight different notes of every octave stand in the following relations to each other: —

$$C : D : E : F : G : \ A \ : B : C^1$$
$$1 : \tfrac{9}{8} : \tfrac{5}{4} : \ \tfrac{4}{3} \ : \tfrac{3}{2} \quad \tfrac{5}{3} \ : \tfrac{15}{8} : 2$$
$$8 : 9 : 10 : 10\tfrac{2}{3} : 12 : 13\tfrac{1}{3} : 15 : 16$$

That is to say, while the tone *C* makes one vibration, the tone *D* makes $\frac{9}{8}$, and *E* makes $\frac{5}{4}$, etc.; or while *C* makes 8 vibrations, *D* makes 9, *E* makes 10, etc.

Consonance and Dissonance.—When two or more "clangs" are sounded together, the result is a highly complex sensation, with a characteristic pleasant or unpleasant feeling attached. If the feeling is pleasant, the resulting complex of fused sensations is called a "consonance" or "chord"; if the feeling is unpleasant, it is a "dissonance" or "discord." Thus *c* and c^1 struck together make a pleasant combination of "clangs"; *c* and *d*, or *c* and *c* sharp, or *c* and its seventh, *b* above, make an unpleasant and discordant combination.

Consonance and dissonance differ from the cases of combination, already considered as belonging to every "clang," with respect to the relative strength of the partial tones when compared with the fundamental tones. In the clang the over-tones are weak in comparison with the fundamental tone; in the chord, or discord, the fundamental tones of the other clangs are strong and stand in powerful relations of consonance or dissonance toward the fundamental tone of the lowest clang among them.

There are degrees of consonance and dissonance which depend upon the amount of coincidence or disagreement belonging to the acoustic waves of the different tones which are combined. With the relation of "the Third" we come upon the borders of a dissonance; indeed, the ancient Greeks and Romans regarded the Third as a dissonance. The major Third and the major Sixth are called "medial consonances" by Helmholtz; the minor Third and minor Sixth are called "imperfect consonances." The following table represents these differences:—

Octave (1 : 2) $\left\{\begin{array}{l} c^1\, g^1\, c^2\, e^2\, g^2\, b\flat^2\, c^3 \\ \hline c^1 \mid c^2 \quad g^2 \quad c^3 \end{array}\right.$.

Twelfth (1 : 3) $\left\{\begin{array}{l} c \mid c^1\, g^1\, c^2\, e^2\, g^2\, b_\flat^2\, c^3\, d^3 \\ \hline \quad g^1 \mid \quad g^2 \quad d^3 \end{array}\right.$.

Fifth (2 : 3) $\left\{\begin{array}{l|l} c & c^1\, g^1\, c^2 \quad e^2\, g^2 \\ \cline{2-2} g & g^1 \quad d^2 \quad g^1 \end{array}\right.$.

Fourth (3 : 4) $\left\{\begin{array}{l|l} c & c^1 \quad g^1\, c^2\, e^2\, g^2 \\ \cline{2-2} f & f^1 \quad c^2\, f^2\, a^2 \end{array}\right.$.

Major Third (4 : 5) $\left\{\begin{array}{l|l} c & c^1 \quad g^1 \quad c^2\, e^2 \\ \cline{2-2} e & e^1 \quad b^1\, e^2 \end{array}\right.$.

It is difficult to give a satisfactory psycho-physical cause for the characteristic feelings of pleasure and pain which accompany those sensation-complexes that are called "chords" and "discords." The cause assigned by Helmholtz is the absence or presence of "beats." It is found that the feeling of dissonance is much increased when the difference in pitch of two tones that lie near together is progressively diminished. This feeling is due to the successive shocks, called "beats," that occur as the pitch of the tones becomes more nearly the same. It reaches its height when the number of the beats is about 30 per second. For example, if b^1 (495 vibrations, in German scale) and c^2 (528 vibrations) are struck together, the number of beats is 33 ($528 - 495 = 33$), and the dissonance is strongly marked. The feeling of consonance Helmholtz considers to be due to the absence of beats. This reason is, however, only a negative one.

It has been proposed to supplement the negative reason given above by a positive one. The pleasure of consonance is thus allied to that which follows all — even dim and half-conscious — recognition of relations. The so-called "tonicity" — or property of being recognized as a constituent of a single fundamental tone — of consonances is thought to afford the reason for the pleasant feeling consonances excite. To this is added the so-called "phonicity" of the consonances; and by this is meant the property which consists in the possession of certain partial tones that are common to *all* tones.

It may well be doubted whether these explanations really explain. Indeed, in the present condition of our knowledge, we are obliged to consider the peculiar and characteristic pleasant quality of consonances, and the opposite quality of dissonances, as fundamental and inexplicable facts of our primary experience.

CHAPTER XI.

THE QUALITY OF SENSATIONS.—Continued.

THE analysis of the qualities of *Sensations of Sight* is much more intricate than that of any of the other senses. They may all be divided, however, into sensations of color and sensations of light. But as we shall soon see, in forming "perceptions" of sight various other classes of sensations are closely blended with those of color and light.

Conditions of Experimenting.—In order to determine under what conditions the quality of visual sensations varies, no little care is required. Changes in quality are found to be dependent upon a variety of causes which, as a rule, act together, but cannot be discriminated by self-consciousness. Quality of sensations—color, for example—depends upon the amount of white light which is mixed with any particular "spectral" color. Only the "color-tones" derived by spectral analysis are found to be "pure" or "saturated." (Probably, as we shall see subsequently, even these are not perfectly so.) The size of the colored object, and the resulting extensity, or breadth, of the sensation, affects its quality; so does the intensity of the stimulus, and the time during which it acts. The same stimulus also produces different sensations when it falls upon different areas of the same retina. The quality of the sensation further depends upon the previous condition of the retina.

VISUAL SENSATIONS CONSIDERED AS RESPECTS QUALITY.

The question before us may then be stated in the following somewhat complex form: What sensations result from the stimulation of a sufficiently small, but not too small, area of the most central part of a normal retina, for a given time, when it is not fatigued, and the eye is at rest, and with neither too great nor too small intensity of a given kind of light?

Excitable Areas for Visual Sensations.—Sensations of light and color are, so far as their peripheral origin is concerned, occasioned by irritation of the rod- and cone-layer of the retina. Probably each element of this structure may be regarded as an isolated sensitive spot, which corresponds, on the one side, to definite excitations from appropriate stimuli; and, on the other side, to the smallest distinct sensations of light and color. In order that two visual sensations may be seen as separate, and lying side by side, two neighboring retinal elements must be excited by the stimulus.

This view is confirmed by the degree of accuracy of which the trained eye is capable. Few observers, for example, can distinguish two stars as two, unless they are apart from 60″ to 70″,—the number differing for different eyes. The angle thus covered corresponds very closely to the size of a retinal element,—namely, from 0.00438 mm. to 0.00526 mm. Moreover, if white lines be drawn on a black ground so closely together as to approximate this limit of vision, they will appear, not straight, but knotted and nicked (see Fig. 75). This fact is due to the action of the stimulus on the rods and cones.

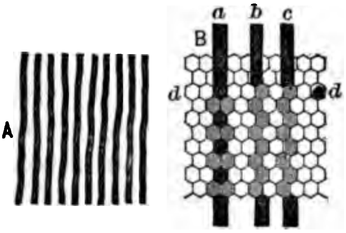

FIG. 75.—A shows the appearance of lines drawn very closely together, which is supposed to be due to their falling upon the nervous elements of the retina in the manner shown by B.

Stimulus of Visual Sensations.—The ordinary form of stimulus which is understood to act directly on the end-organs of vision is light, — or certain exceedingly rapid oscillations of so-called luminiferous ether. The actual immediate excitant of the rods and cones we have seen, however, to be — it is probable — certain photo-chemical changes of an unknown character. But these changes, and so the sensations of color and light, may be occasioned by other forms of stimulus than light.

Mechanical stimulus of the eyeball by pressure upon it with the finger or a blunted stick results in the production of so-called *phosphenes*, — disks of light with darkly colored edges. A blow on the head, or an electrical current, may cause optical sensations. The quality of the sensations aroused by the electrical stimulation seems to change with the direction (ascending or descending) of the current. The retina has also a "light of its own" (*Eigenlicht*); for its nervous elements are rarely or never inactive, but have a continuous *tonic* excitation. This "own-light" is very changeable and seems to have a rhythmic movement. It is probably due to the photo-chemical changes produced by the changing character and amount of the blood-supply.

In this connection, we may note the remarkable phenomena of so-called "color-audition." In rare cases, the hearing of a sound is spontaneously accompanied by the seeing of a color, which varies with the sound heard. A case in France has recently been reported — hereditary in father, and in son and daughter — where the vowels, open or mute, when pronounced, provoked definite color-sensations. Thus, *a*, *a*' and *â*, excited the sensation of red or salmon color; *e*, *e*', or *ê*, of white; *i*, of black, etc. Certain obscure cerebral peculiarities seem to be implied in idiosyncrasies of sight like this.

The Various Color-tones. — It has already been said that only by use of the spectrum can we obtain "pure" or "saturated" color-tones. This instrument, on account of the different refrangibility of the different colored rays which compose the compound ray of white light, is able to analyze the color-tones. It is thus discovered that the compound sensation produced by sunlight is made up of simple components corresponding to oscillations ranging all the way from about 370 billions to about 900 billions per second. The quality of the simple color-sensations discovered by this analysis varies characteristically — as the following table will help to illustrate — according to the changes in number of the oscillations.

NAME OF FRAUNHOFER'S LINE.	NUMBER OF VIBRATIONS PER SECOND.	WAVE-LENGTHS IN THE AIR.
	Billions.	Millimeters.
B	450	0.000 6878
C	472	0.000 6564
D	526	0.000 5888
E	589	0.000 5260
F	640	0.000 4843
G	722	0.000 4291
H	790	0.000 3928

The table shows that rays of light which have a number of oscillations less than 450 billions per second, so far as they affect the retina at all, occasion the sensation of red. This sensation does not change quality greatly as the number of oscillations rises from 450 to 470 billions. Beyond this limit (*C*), however, the quality of the color-sensation changes rapidly, takes on a yellowish tone (orange), and finally at 526 billions (*D*) corresponds to a decided yellow. This sensation then becomes greenish, as the number of oscillations increases, until they reach about 589 billions per second, when green (*E*) appears. The green then becomes bluish, and at 640 billions blue (*F*) begins to arise. From this on to about 722 billions (*F*–*G*) the colors lie between the blue and the violet until the decided violet comes to view.

The spectrum has no sharply defined limit at either end. At both ends it passes gradually into black, but more gradually at the violet than at the red end.

Brightness of Color-tones. — The impression made by the colors lying immediately about *D* (*D–E*) is stronger than elsewhere. Or, as we should say, the colors are naturally "brighter" here (about the green-yellow of the spectrum) than the other colors. This difference cannot be due to the objective energy of the rays of light, whether as measured by their chemical or their calorific effect. It must be due, then, to the structure of the retina, and its peculiar sensitiveness to stimulations by the color-rays of this region of the spectrum. Crimson light requires many times more energy than green in order to be strong enough to read by it.

Least Perceptible Variations of Colors. — The sensitiveness of the retina to slight variations in quality of the color-tones is also different at different portions of the spectrum. In general, it is greatest in the blue and blue-green regions (*D* and *F*). The precise ratios which express this difference of sensitiveness to slight variations at different portions of the spectrum are given somewhat differently by different observers.

The Composite Nature of Colors. — Our ordinary color-sensations, like those of musical sounds, are not pure and simple, but complex. For the analysis of these sensations, however, unlike that of musical sounds, the method of conscious discrimination is of no avail. Sensations of color cannot be mentally analyzed into their constituent elements. They persistently maintain, in consciousness, that single and uncompounded quality which has resulted from the fusion of the different elements supplied by the rays of different color-tone.

When the wave-lengths of the two colors that are mixed vary but slightly from each other (a few billion oscillations per second), the result of their mixture may be recognized as a "shade" of one of the same two colors. Thus many shades of so-called "orange" would readily be recognized as mixtures of yellow and red. That certain blues are greenish, or greens bluish, is manifest to everybody.

The color-impressions formed by mixture are not all different from each other. So that if we were to mix color-tones that lie apart at all possible distances along the spectrum, the number of resulting compounds would not be unlimited. In fact, the number of the resulting sensations would be much less than the number of the compound physical processes which stimulate the retina. The quality of these colors formed by mixture depends upon the place in the spectrum from which the simple color-tones are selected, and upon their intensity. Moreover, we may discover two ways of advancing, by this process of mixing color-tones, to any of the composite colors. We may pass, for example, from yellow to blue, either through green-yellow, green, and blue-green, or through orange, red, purple, and violet.

Number of Colors Distinguishable. — Newton formed a sort of octave of fundamental colors, consisting of the seven members, — red, orange, yellow, green, blue, indigo, and violet. But there is really no basis for this classification, either in science or in ordinary experience and usage. Indigo, as a kind of semi-tone between blue and violet, has no more right to a place in this scale than have many other intermediate tones; the same is substantially true of orange. The purples, which lie on the scale between the blues and the reds, are entirely overlooked in this classification; the browns, too, find no place anywhere.

Before raising the question as to how few in number are the colors which may be called "fundamental," we may fitly notice that the number of color-tones actually discernible by the human eye is very great. One authority places it, in oil-colors, at 100; but in the spectrum another authority thinks it possible to discover 230 distinct tints. Herschel considered that the workers on the mosaics at Rome must have distinguished 30,000 different color-tones. If we allow for differences of brightness and purity of tone, the actual number of sensations possible with this sense, may well reach into the hundreds of thousands.

Complementary Colors. — If certain color-tones, having a given intensity, are united on the retina, the result is a sensation wholly unlike either of the two thus united. This sensation we call "white"; and the two colors which produce it by their admixture are called "complementary." Such a mixture may be obtained in various ways, — *e.g.* by superimposing two spectral rays, by blending the reflected images of two colored wafers, or the visual impressions of colored surfaces on a revolving top or wheel, etc.

Following is Helmholtz's table of complementary colors:

COLOR.	WAVE-LENGTH.	COMPLEMENTARY COLOR.	WAVE-LENGTH.	RELATION OF WAVE-LENGTH.
Red	2,425	Green-blue	1,818	1,334
Orange	2,244	Blue	1,809	1,240
Gold-yellow	2,162	Blue	1,793	1,206
Gold-yellow	2,120	Blue	1,781	1,190
Yellow	2,095	Indigo-blue	1,716	1,221
Yellow	2,085	Indigo-blue	1,706	1,222
Green-yellow	2,082	Violet	1,600	1,301

The complementary colors for different persons are not always precisely the same; indeed, they may differ for the two eyes of the same person.

Quality as related to Intensity. — When the intensity of the light approaches either a maximum or a minimum, important changes in the quality of the resulting sensation occur which are independent of changes in the wave-length. At the maximum intensities all distinctions of color-tone cease, and even homogeneous rays appear white. Before reaching this maximum, red and green pass over into yellow. Near the minimum intensities every color-tone, except "saturated" red, becomes colorless when seen alone on a perfectly black ground. The different color-tones disappear at different degrees of intensity of the light, — green remaining visible in the weakest light.

Quality as related to Time. — Changes of color-tone take place when the time during which the light acts upon the retina is reduced to a minimum. A certain "light-mass" (considered as *the product of duration by intensity*) is necessary for a sensation of light or color. Sensations of saturated color can be produced by instantaneous illumination of the spectrum with an electric spark; but more time is needed to produce these sensations with a weaker light.

On this subject a recent investigator has arrived at the following conclusions: (1) As the illumination increases, the rate of the waning of the sensation decreases. (2) For weak illuminations and brief stimulations, the waning of the sensation is nearly inversely as the square of the illumination. (3) The color of the light has no effect. [This point is, however, disputed by other observers.] (4) Exposure of the eye to a dark room increases the sensation.

Quality as related to Zones of the Retina. — Important changes in the quality of our sensations of light and color are dependent upon the place of the retina on which the stimulus falls. For purposes of experiment the entire organ has sometimes been divided into three zones, — a central or polar, a middle, and an outer or peripheral. These regions seem to differ as respects the distinctness, the quality, and the intensity, of the sensations produced by the same stimulus. In general, while an indefinite number of clearly distinguishable color-tones are possible when the light falls on the polar zone, this number is reduced to comparatively few impressions on the middle zone; and all color-tones gradually become indistinguishable on passing through the outer zone. At a certain distance from the centre, blue and yellow alone are seen; and farther away, none of the color-tones are apparent. Red changes through orange and violet to blue, as we pass toward the periphery of the retina. Blue and yellow become paler, — apparently in proportion to the amount of green in them.

The best evidence seems to show that the sensitiveness of the retina to sensations of light — unlike that of color-tones — increases toward the peripheral region. The opposite of this view has, however, been maintained. Recent and apparently careful experiments fix the maximum sensitiveness to light at a distance of 20°–25° horizontal, and 12°–15° vertical, from the retinal centre. The lower portion is found to be less sensitive than the upper; and possibly the temporal side is more sensitive than the other side of the retinal area. The cause of this increase in sensitiveness toward the periphery is unknown. It has been conjectured that this is due to the highly developed structure of the rods which act as mirrors to reflect the light.

Phenomena of Color-blindness. — In certain cases, defects of vision exist which seem to show that the entire retina of some individuals resembles the middle or the outer zone of the normal retina. Such individuals are said to be "color-blind." Two classes of cases are distinguished. In the one class, which is much the more frequent, a partial or complete insensitiveness to red rays exists; the spectrum may then be said to be shortened at the red end.

In other cases this insensitiveness applies also to the green or blue-green or green-yellow or "blue-violet" color-tones. It has been proposed to divide all cases of color-blindness into two groups,—the "red-blind" and the "green-blind."

Important modifications of the sensations of light and color are due to the *previous condition of the retina*, or to the *contemporaneous condition of the parts adjoining* that on which the stimulus falls. Under the first head fall the phenomena of "inertia" and "exhaustion"; under the second, the phenomena of "contrast." In both classes of cases there is some evidence to show that obscure complications, of a cerebral rather than a peripheral origin, have an influence on the result. This should be borne in mind in considering those relations of quality, and its changes, which are now to be examined.

Phenomena of After-images.—If we close our eyes after looking for a time intently at any bright object, an image of this object remains for some time and only gradually fades out of sight. Such an image is called a "*positive* after-image," because its bright and dark parts correspond to those of the original object. This delay in the fading away of the image from the retina is said to be due to the physiological "inertia" of the organ.

But if we continue to regard the after-image, we observe that its parts undergo a change of color. The white changes into greenish blue; then into indigo-blue, violet, and finally a deep rose color. If we look at a green surface for some time, and then fix the eye upon a white surface, the latter will become of a red color. In general, the color which this class of after-images assumes is the color "complementary" of the color of the object. These images are therefore called "*negative* after-images." Moreover, the color-tones of the spectrum can be made to appear brighter by looking at them immediately after having filled the eye for some time with the complemen tary color. It thus appears that some spectral colors are not completely "saturated." Such phenomena are said to be due to the principle of "exhaustion." The end-organs — and also, it is probable, the central organs — after use upon one color-tone, for a time lose their sensitiveness to the stimulus which produces this color-tone.

Phenomena of Contrast. — A bright object appears brighter with surroundings darker than itself, and darker, with surroundings brighter than itself. In the case of gray disks on a background darker than themselves, the increase of brightness is found to be closely proportional to the difference in brightness between the disk itself and the background; but it is probably independent of the absolute brightness of the latter. This phenomenon is called "contrast," — the word in this instance being applied to brightness of color-tone.

When colored instead of white light is used in experimenting under this law, phenomena similar to those of complementary colors are obtained. For example, a small square of white on a surface of green, when covered with a transparent sheet of tissue-paper, appears as red on a surrounding surface of a whitish hue; on a red ground it appears as green, on a blue ground as yellow, and on a yellow ground as blue.

As yet we have no full and satisfactory explanation of the phenomena of contrast. Helmholtz at one time ascribed it to deceptions of judgment, such as we are familiar with in estimating distances. But this theory seems strained and remote from the facts. A satisfactory partial explanation is found in the physiological principle that stimulus of any element of the retina tends to spread over contiguous elements; and, in turn, the effect of the stimulus on the elements on which it falls is modified by the condition of the contiguous elements. But besides all this, we seem compelled to refer to the influence of obscure cerebral conditions that are dependent upon the associated action of the nervous elements of the cerebral centres themselves. The necessity for this will be more apparent when we come to consider the formation of visual perceptions.

GENERAL THEORY OF VISUAL SENSATIONS.

The complicated character of the sensations of light and color, as respects their quality, renders it peculiarly difficult to frame any general theory which shall embrace and satisfy all the phenomena. The groups of facts, which chiefly need theoretical explanation, are the following: (1) It is possible to produce all the color-tones by mixing certain fundamental colors, which must be at least *three* (and probably, better, four) in number. And the intermediate shades lying between any two proximate color-tones can be produced by mingling these color-tones. (2) The saturation or purity of the color-tones depends upon the intensity of the light; and all the color-tones may be graded downward, as it were, into colorless light. (3) Any two colors of the spectrum chosen at proper intervals along its scale, when mixed, will produce white. (4) The theory must explain the phenomena of after-images, color-blindness, and contrast, either by the way in which it regards the preceding classes of facts, or in some secondary manner derived from, and based upon, these facts.

Young-Helmholtz Theory of Visual Sensations. — Among the several theories proposed for the explanation of the foregoing phenomena, that brought forward by Young and elaborated by Helmholtz has been most widely accepted. This theory takes its point of starting from the fact that we can produce all the many color-tones by mixture of a few so-called "fundamental" colors. It assumes three fundamental colors. Of these, green must be one, because green has no complementary color. The other two may then be taken from the two ends of the spectrum; they are red and either violet, or indigo, or blue.

It is then further assumed that, in every sensitive portion of the retina, three kinds of nervous elements exist. The excitation of each of these elements separately would produce only that kind of fundamental color-tone which is peculiar to the specific elements excited. We may say, then, that there are in the retina elements of "green-color sensation," elements of "red-color sensation," and elements of "blue-color sensation."

But every actual sensation is a complex affair. Its character is determined by the relative intensities with which the different kinds of nervous elements are combined to produce it. This may be illustrated by the accompanying diagram (No. 76), where the curved lines *R*, *G*, and *B* represent the three fundamental colors, and the curves described by them show the strength of the influence exercised by these colors in forming the complex result; while the perpendicular lines indicate the several color-tones of the spectrum.

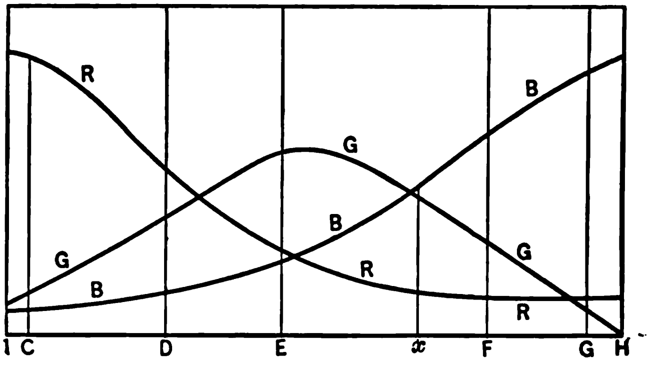

FIG. 76.—Diagram from Fick, illustrating the Young-Helmholtz Theory. (For explanation, see the text.)

The Young-Helmholtz Theory should be gratefully recognized as a brilliant attempt at explaining the phenomena of sensations of light and color. It is most successful with the facts that relate to the mixing of colors. It is perhaps most unsuccessful with the phenomena of color-blindness, contrast, and the dependence of color-tones on time, place of the retina stimulated, etc. Those who dispute it consider, and apparently with good reason, that its failure on these points is decisive against it. For example, it does not appear that the colors wanting in the different forms of color-blindness correspond to the three fundamental colors of the normal system. Red-blind persons ought, according to this theory, to see white as greenish blue, and green-blind persons ought to see it as purple. But apparently both see white as we all do. Moreover, pure yellow is not displaced, in the spectrum of the color-blind, in the direction of green, or pure blue in the direction of violet.

It must be confessed that the more elaborate theories which have been proposed to take the place of that known by the name "Young-Helmholtz" are scarcely more satisfactory. We shall refer, however, to one or two of them.

Hering's Theory of Visual Sensations. — This authority insists that we must regard the changes of sensation through which we pass when viewing the different shades of gray, from white to black, as analogous to other color-sensations. Moreover, he considers that *six*, instead of three, *color-tones must be assumed as fundamental*, in order to produce all the other color-tones by admixture of these six. Hering, therefore, proposes the following pairs of fundamental color-tones, — black and white, green and red, blue and yellow. The first member of each pair (black, green, and blue) he considers to be the result of a process of "construction" of visual substance. The second member of each pair (white, red, and yellow) he ascribes to the "destruction" of such visual substance.

Apparently decisive objections to this theory have been brought forward. Among them one of the most conclusive seems to be the following. A light composed of red and green may be made to seem to the eye the same as a light composed of yellow and blue. If, then, the eye is "fatigued" to red, instead of the red-green mixture appearing greenish, and so distinguishable from the yellow-blue mixture, they both appear the same to the fatigued eye.

Wundt's Theory of Visual Sensations. — Another view emphasizes a supposed difference in the processes, rather than in the kinds of retinal elements, belonging to the different color-tones. A very elaborate example of such a view is the theory of Wundt. We state only a few of its principal features. (1) The retina may be assumed to be in a constant state of internal excitation, to which the sensation of *black* corresponds. Hence when other excitations are absent, we have the sensations of more or less darkness. (2) Every external excitation sets up two kinds of processes in the retina, — one a color process ("chromatic"), the other a colorless process ("achromatic"). These two processes follow different laws. (3) The colorless (achromatic) process is of a uniform photochemical character; and its intensity in uni-colored light is dependent partly on the intensity of the light, and partly on the length of the waves. It reaches a maximum at yellow, and falls off in both directions. (4) The color (chromatic) process is of a manifold photochemical character, and it changes by insensible degrees with the length of the wave. (5) Each process of excitation outlasts for a certain time the stimulus which occasions it, and exhausts the sensibility of the sensory substance for the stimulus.

By combining these features, Wundt thinks that all the phenomena, except those of contrast, which are due to a cerebral origin, may be accounted for.

Symbolism of Visual Sensations. — The foregoing laws of the changes in visual sensations, and the nature of the theory which must be devised to account for them, have been represented to the eye by various ingenious devices. Among them the most common is the so-called color triangle (see Fig. 77). In this triangle the different color-tones may be regarded as lying along a curved line, from red to violet; and the difference, in the scale, between any two color-tones is measured by the angle made by two lines drawn from the point *W* through the points occupied on the lines by those two color-tones.

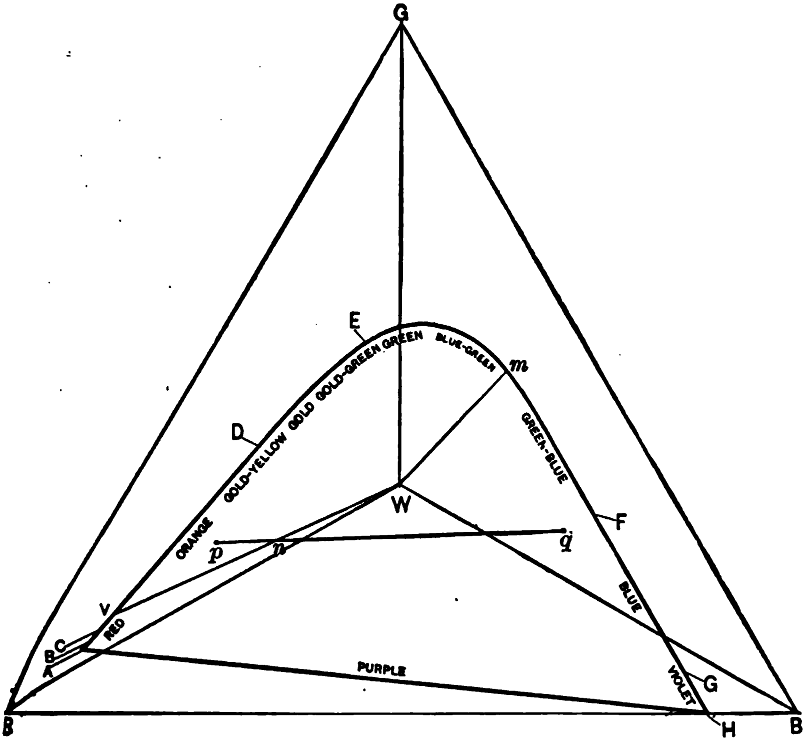

FIG. 77.—Color-triangle, from Fick. (For explanation, see text.)

Figure 78 is a scheme for showing the relations of color-tones by two concentric circles, each color in one circle corresponding to its complementary color in the other circle. In the phenomena of contrast, if the color inducing the contrast be represented by a segment of the inner circle, the coincident segments of the two circles represent the direction in which the induced change is moving. For example, the segments representing green and purple coincide, and so do those representing red and blue-green. Green on a red ground is, therefore, modified as it would be if blue-green were mixed with it; and red on a green ground, as it would be if purple were mixed with it.

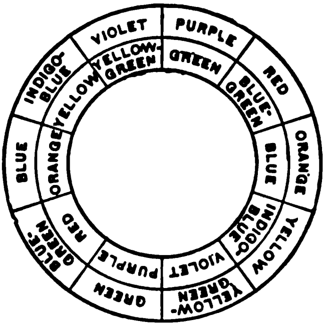

FIG. 78.—Scheme for showing the Relations of Color-tone (see text).

CHAPTER XII.

THE QUANTITY OF SENSATIONS.

BY an act of mental analysis, which all can perform, the *amount* of sensations is distinguished from their kind, the *intensity* from the quality. The nature of this analysis may be illustrated by familiar examples: such are the "dying away" of the tone when a skilful player draws his bow with gradually diminishing force over the string of a violin; or the increase in the noise made by a bell as we approach the place where it is sounding. So, too, we readily recognize changes in our sensations when more of pressure or of temperature, whether hot or cold, is applied to the skin.

Ordinary Experience Insufficient. — It is also obvious, however, that the measurement of the amount of our sensations by consciousness directly, is very inexact. This is true even when the sensations compared belong to the same sense. We should hesitate, for example, to say whether a given noise were four, or five, times as loud as one immediately preceding. And no one would think of affirming the exact fraction, in hundredths, of the amount by which the brilliancy of one lamp surpasses that of another.

The inadequacy of such direct comparison of sensations in consciousness becomes more apparent when we attempt to place sensations of the different senses side by side. We apply, indeed, terms of intensity — such as "weak," "very weak," "strong," "very strong," or "moderate," etc. — to all kinds of sensations. But we should consider it absurd to affirm: The rose smells as sweet as the grass looks green; or, The coffee is as strong as the sky is blue.

That the measurement of the quantity of our sensations is complicated with changes in their characteristic quality has already been remarked. Increase in the brightness of a color invariably changes its characteristic color-tone. The strong smell of musk or assafœtida is not the same kind of sensation as the weak smell of these objects. Only in the case of musical tones are we able at the same time carefully to attend to both the quantity and the quality of our sensations, and so approximately determine that the former is changing while the latter remains unchanged. Even in the case of these acoustic sensations, any considerable change of intensity changes also the relation of the over-tones to the fundamental tone, and so the "tone-coloring" of the "clang."

Two Questions relating to Quantity.—The general inquiry into the quantity of our sensations involves two subordinate questions. These are: (1) How little, or how much, respectively, of each kind of stimulus produces the least, or the greatest, amount of resulting sensation, of which the mind is capable? and (2) What is the law regulating the relation in which changes in the intensity of sensations, as estimated in consciousness, depend upon changes in the intensity of the external stimuli? The first question is a *question of the limits* within which sensations may vary in quantity and remain sensations of the same sense. The second question is a *question of the uniform relations* (or law) which are maintained, within the limits, among the various sensations compared.

Difficulties of the Investigation.—The answer to both of the foregoing questions is accompanied by many difficulties. It has just been shown that our subjective standards for measuring the amounts of our sensation-experience are very inadequate. The objective standards for measuring the quantities of the stimuli which occasion the sensations are also far from satisfactory. This is, of course, especially true of the senses of taste and smell; since we do not even know what properties smellable and tastable substances must possess in order to irritate the nerves of these senses. So is the measurement of the stimulus which occasions sensations of temperature made difficult by the fact that its amount is dependent upon the zero-point of the skin itself,—a matter that varies greatly and is always difficult of determination. For sensations of pressure, light, and sound, we can make the necessary determinations with a greater approach to exactness.

The "Least Observable Difference." — There is, however, one kind of measurement respecting the quantity of sensation which can be made in consciousness with a great degree of accuracy. Suppose that two sensations of the same quality are produced, either in quick succession upon the same area of the organ of sense, or simultaneously upon corresponding areas of the organ, by amounts of stimuli that are equal, or very nearly equal: then the attentive mind can tell with considerable accuracy whether the intensities of the two sensations are exactly equal, or differ minutely. This difference of quantity in the sensations which marks the limits of the mind's power of discernment is called "the least observable difference." *The problem of measuring accurately the quantity of sensations becomes then the problem of determining the least observable difference of quantity for each kind of sensations, and for every point along the scale of degrees of quantity.*

[Much debate has arisen over the question: Is the least observable difference of two sensations itself a constant quantity? Into the nature and merits of this debate we cannot undertake to enter. In the way in which the question is often discussed, the whole matter is, in our judgment, resolved into misleading figures of speech. There is no mental entity, or mental state, corresponding to this term, "least observable difference."

For example, if the additon of n to the stimulus S is the smallest amount that will so change the mental state x as to make it pass over into a state x', — which latter state the mind judges to be a state of increased amount of sensation, — then we can recognize and accept this fact as a fact. It does not follow, however, that we may argue that $x' - x = \Delta$, and that this Δ is itself entitled to be called a " least observable difference," as though it were a fixed quantity of mental experience. There are in consciousness the sensations x and x'; and we judge one to be greater than the other. But Δ (or $x' - x$) is only a fiction growing out of a figurative application of mathematical terms to subjects that elude all correct representation by such terms.]

Methods of determining the Limits. — There are two ways of determining *the lower limit*, or least amount of stimulus which occasions any sensation at all. We may choose a weak stimulus, that is, however, slightly stronger than is necessary to produce a sensation when applied; and we may then diminish it by minute gradations until the exact point is reached and noted at which it ceases to produce any sensation at all. Or we may choose, at first, a stimulus too weak to produce any sensation, and then increase it by gradual minute increments until the point is reached, and noted, at which some sensation is produced. By these two methods the "sensitiveness" of the different areas of the different organs, under different circumstances, may be tested.

In the cases of sight and sound the attempt to fix the lower limits of the sensations is greatly embarrassed by the fact that the organs of sensation are rarely or never perfectly free from excitation beyond our control. The eye has its "own-light"; the ear is never in "absolute stillness," or freedom from stimulus by the movements of surrounding structures of the head.

The *upper limit*, or maximum amount of stimulus which results in producing sensations of each class, cannot be determined experimentally. Large quantities of stimulus not only fatigue and endanger the nervous structure upon which they act; but they also arouse such an amount of painful feeling, and of influence from allied forms of sensation, as to overwhelm the particular kind of sensation whose quantity it is desired to measure. Very concentrated odors or solutions, exceedingly intense lights and noises, are not simply smelled, or tasted, or seen, or heard; they are all painfully *felt*, as it were, over extended areas of the body.

We may affirm in general, however, that the "capacity" of each sense varies directly as the amount of stimulus which it can receive. Let $\frac{1}{S}$ stand for the measure of the sensitiveness of the sense, and C stand for the measure of its capacity; then $\frac{C}{S}$ will represent the "circuit" or range of the sensations of which the sense is capable.

Methods of determining the Least Observable Difference. — There are three different ways of measuring the sensitiveness of the mind to minute changes in the amount of sensations as dependent upon changes in the intensity of the stimuli. Of these the first (1) is called "the method of least observable difference." Two ways of applying the principle of this method are to be noticed. If we follow one of these ways (sometimes called "the method of mean gradations"), we first select two sensations, produced by two different intensities of the stimulus, which are separated by a clearly perceptible interval as respects their quantity (A and O), and we then inquire, what intensity of the stimulus is necessary to produce a sensation that seems to lie exactly midway (M) between these two? In other words, we try to locate the sensation M as exactly half-way between A and O. We then seek to put K half-way between A and M; and so on, until a scale of graded least observable differences is reached. But if we follow the other way of applying this method (sometimes called "the method of minimum changes"), we seek directly to judge, all along the scale of intensities, what change of stimulus is *just* enough to produce a change in the amount of the resulting sensation.

(2) "The method of average error" consists in trying to fix upon an amount of stimulus which will produce a sensation that *seems* exactly equal to another sensation selected as a standard of estimate. Repeated trials of this sort result, of course, in a number of guesses, some of which are more or less out of the way. By averaging all the trials, the degree of sensitiveness for that sense, at that place in the scale, is determined.

(3) In "the method of correct and mistaken cases," trial is made to see how many right, and how many wrong, guesses occur in the effort to detect minute additions or subtractions in the amount of stimulus. Thus: let $n =$ the whole number of guesses, and $r =$ the number of right guesses; then $\frac{n}{r} =$ the sensitiveness to minute differences, for that particular position in the scale, and particular kind of stimulation. In this way a scale can be manufactured, — the positive value of $\frac{n}{r}$ being kept unchanged.

All three of these methods are alike in that they aim at constructing *a scale* of degrees of sensitiveness by determining the least observable differences, for all the senses, and for the various gross amounts of stimulus, under a variety of circumstances.

The Law of Weber or Fechner. — The attempt to formulate the results reached by thousands of experiments, by each of the foregoing methods, has resulted in a "law" known by the name of Weber, or Fechner. The former of these investigators propounded the principle of this "law"; the latter has defended and elaborated it by a vast amount of research. Weber's law admits of statement in several forms: (1) The difference between any two stimuli is experienced as of equal magnitude in case the mathematical relation of those stimuli remains unaltered. (2) If the intensity of the sensations is to increase by equal absolute magnitudes, then the relative increase of the stimulus must remain constant. (3) The strength of the stimulus must increase in a geometrical proportion in case the strength of the sensation is to increase in an arithmetical proportion.[1]

Value of Weber's Law. — Familiar experience makes us aware that the difference in the amount of our sensations does not increase in direct arithmetical ratio with the increase in the intensity of the stimuli which cause the sensations. For example, the difference between the shadow cast by one taper and that cast by two is readily observable in a dimly lighted room, but is wholly unobservable in open sunlight; or the strength in the ticks of two different clocks can be nicely discriminated, but not the amount of noise made by two successive discharges of a cannon.

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[1] A simple statement of Weber's principle may be given as follows: Let $H =$ the intensity of the light of one-half of a white field; $\frac{H}{100} =$ the smallest fraction of stimulus added to H that will produce an observable increase in this intensity; and $H + \frac{H}{100} =$ the intensity of the other half of the same field. Then let $S =$ the sensation produced by H, and $S + s =$ the sensation produced by $H + \frac{H}{100}$: s will now, of course, represent the so-called "least observable difference" at this point in the scale. We have, then, H produces S; $H + \frac{H}{100}$, or $\frac{101}{100} H$, produces $S + s$; $\frac{101}{100} H + \frac{\frac{101}{100} H}{100}$, or $\frac{101}{100} \cdot \frac{101}{100} H$, produces $S + s + s$; and so on. That is to say, if s is to be kept of the same magnitude, then H must be *multiplied* by the same magnitude $\frac{101}{100}$.

To the principle involved in this familiar experience Weber's law attempts to give an exact scientific expression. It has been well said[1] that its value depends upon its furnishing a means of comparing the sensibility of different incommensurate senses. As formulated in terms of the method of correct and mistaken cases, it means that the standard by which the relative qualities of our sensations are judged, is independent of the absolute magnitude of the stimuli, but depends solely on the ratio of the stimuli. As formulated by the method of average error, it means that the probable error will not be influenced by a change in the absolute magnitude of the stimulus according to which the adjustments are to be made.

After years of diligent experimenting, in countless numbers of cases, the so-called law of Weber is weaker rather than stronger, in its claim to be an exact expression of the universal relation between changes in the intensity of the stimulus and changes in the amount of the resulting sensations. The most that can be said is this: *The law summarizes many facts reasonably well within a certain range of sensations lying near the middle of the scale of quantity, and for certain of the senses.*

Least Observable Difference in Sensations of Pressure. — Various causes affect our sensations of pressure, as respects their smallest discernible quantity. Among them are the presence of muscular sensations, mingled with sensations of the skin (temperature, etc.), the locality to which the stimulus is applied, the interval of time allowed after applying the stimulus, etc. Weber ascertained that, when the interval was 15 to 20 seconds, under the most favorable circumstances, 14½ could be distinguished from 15 grammes of pressure, 14½ from 15 ounces, etc. That is, some persons distinguish weights which differ in the ratio of 29 : 30, when laid on the volar side of the last phalanx of the finger. If allowed to raise and lower the weights, the niceness of the discrimination is increased so that the ratio becomes 39 : 40.

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[1] By Professor Jastrow, in the American Journal of Psychology, 1888, p. 298.

More recent experiments seem to show that the quotient of sensitiveness for sensations of pressure varies greatly with the different absolute values of the weights employed. One calculation places it at $\frac{1}{43.6}$ for weights of 300 grammes to $\frac{1}{78}$ for weights of 3000 grammes. Another series of experiments gave results (somewhat doubtful, however), varying as the following table indicates: —

Absolute weight. Grammes.	Least observable difference. Grammes.	Quotient of Sensitiveness.
10	0.7	$\frac{1}{14}$
50	1.7	$\frac{1}{29}$
100	2.4	$\frac{1}{42}$
200	3.6	$\frac{1}{55}$
300	4.6	$\frac{1}{65}$
400	5.2	$\frac{1}{77}$
450	6.5	$\frac{1}{69}$
500	25.5	$\frac{1}{20}$

When the weights are raised, it would appear (according to the latest experiments) that we are influenced in our estimate of their magnitude by the speed with which they rise. Indeed, it is held by some observers that the entire validity of Weber's law in such cases depends upon the fact that a just observable difference in the speed of their rise corresponds to a just observable difference in their weight.

Lower Limits of Sensations of Pressure. — The absolute sensitiveness of the different areas of the skin to sensations of pressure differs exceedingly. This difference is due to a variety of circumstances, — such as, the number and sensitiveness of the nervous elements present in the skin, the thickness of the skin, its tension over the underlying parts, attention, use, habit, etc. Following are the numbers which have been found to measure the lightest weight which would produce a sensation on various parts of the body: on the forehead, temples, and dorsal side of the fore-arm and hands, 0.002 gramme; volar side of the forearm, 0.003 gramme; nose, lips, chin, eyelids, and skin of abdomen, 0.005 gramme; volar side of the fingers, 0.005–0.015; finger-nails and skin of the heel, 1 gramme.

Quantity of Temperature-sensations. — It is nearly impossible to apply Weber's law to sensations of heat and cold. We do not know exactly what to measure as constituting the quantitative changes in temperature. The temperature of the so-called "zero-point of the skin" is very changeable. The one rule which seems most general is this: *The skin is most sensitive to changes which lie near its own zero-point.* The nicest discrimination of two temperatures is attained where one lies just a little above, and the other just a little below, this zero-point. Under such circumstances, changes will be read by the skin amounting to only $\frac{1}{6}$° or $\frac{1}{10}$° F.

We have already seen (p. 239 f.) that the sense of temperature depends for its fineness upon the extent and locality of the surface of the skin which is excited. Since the modern discovery of heat-spots and cold-spots that can be located, with different degrees of intensity and in varying numbers, on the different areas of the body, the table of sensitiveness to temperature has been greatly changed. In general, it may be said that the sensitiveness of the forehead to cold is intense, but to heat only moderate; that of the breast to cold moderate along the sternum, and elsewhere very intense, while to heat it is only moderate, except near the nipples; that of the back everywhere very intense to cold, and only moderate to heat; while in all parts of the hand the intensity of sensitiveness is nearly alike for both cold and heat.

Measure of the Stimulus for Sensations of Sound. — If the quantity of our sensations of sound varied in direct proportion to the intensity of the stimulus, it would be impossible to execute nicely shaded passages of music. How exactly the law of Weber applies to musical sounds, it is difficult to tell because the experiments are necessarily complicated with so many conditions. We have already seen that no considerable increase in the intensity of a tone is possible without changing its timbre. Pitch also has a great influence upon our estimates of intensity. In experimenting with noises the absence or presence of so-called "entotic" sounds (sounds that originate in the action of physiological changes within the organs contiguous to the inner ear) is of great influence. The order in which the sounds are heard seems also to have something to do with our impressions of their loudness. Of two successive equal sounds the second regularly seems the greater.

It is also a matter of some dispute whether the intensity of the acoustic stimulus is to be measured by the product of the mass of the falling body into the height from which it falls $(m \times h)$; or by the product of the mass into the square root of the height $(m \times \sqrt{h})$. The former mode of measurement is probably more correct.

Weber's Law applied to Sensations of Sound. — By making large allowances for relations of time, and using the method of correct and mistaken cases, some of the older experimenters succeeded in establishing the law of Weber as fairly accurate for sensations of noise of moderate intensity. More recent researches still leave the matter in doubt, however; at any rate, unexplained variations of the so-called law arise at various points along the scale, and near the upper and lower limits it seems to fail completely.

The sensitiveness of the ear for minute differences in the intensity of sensations of tone seems to be greater than that for noise. But here the variations from Weber's law are numerous. The following tables sum up the results of two recent, extended sets of experiments. In the first the unit of measure for the strength of the tone was taken "below the threshold," and the fraction of "discriminative sensibility" is given for the different places on the scale marked by different multiples of this unit of intensity. [The threshold value was about 1.6, as expressed in units of the same intensity.]

Intensity.	Discriminative sensibility.	Intensity.	Discriminative sensibility.
5	.135	10^6	.140
20	.108	10^7	.153
10^2	.112	10^8	.161
10^3	.118	10^9	.178
10^4	.116	10^{10}	.225
10^5	.131	10^{11}	.350

Of course, if Weber's law held exactly the fraction in the second column of the table would remain unchanged.

By using tuning-forks and the method of "just observable difference," another observer obtained the following results: —

Number of vibrations	64	128	256	512	1024	2048
Just observable difference	.149	.159	.232	.251	.218	.362
Fraction demanded by Weber's law	.15	.30	.60	1.20	2.40	4.80

In this table we note a wide discrepancy between the fraction of just observable difference as determined by actual experiment and that demanded by the law of Weber.

Lower Limit of Sensations of Sound. — The least amount of sound which will excite sensation depends, of course, upon many circumstances. Of these the most important is as nearly perfect stillness as it is possible to obtain. Under the most favorable conditions an incredibly small amount of energy expended on the ear will excite sensation. One observer has fixed the limit at the noise made by a cork ball of 1 milligramme (about 0.0154 grain) weight falling from a height of 1 millimeter (0.03937 inch). Another has calculated that an amplitude in the molecules of the air not more than $\frac{1}{10}$ the wave-length of green light, doing upon the ear-drum only about $\frac{1}{17}$ of the work done upon the same surface of the pupils of the eye by a single candle, will evoke a sensation of sound. Yet another calculation fixes the energy at the threshold, for a musical tone of 440 vibrations, as about $\frac{1}{6}$ that for sight (*e.g.* of the light of a star of the sixth or seventh magnitude).

Astronomers were for a long time, before the promulgation of Weber's law, aware of the fact that the magnitudes of the stars are not to be classified according to their absolute brightness as determined by photometric observations. Sir John Herschel assumed this when he made the series of magnitudes run $1:2:3:4$, etc., while the series according to photometric brightness run $1:\frac{1}{4}:\frac{1}{9}:\frac{1}{16}$, etc. Something like the same principle is required to account for our ordinary experience with sensations of light. The finer gradations of shade in a lithograph or photograph are not lost when we take it from the open sunlight into a dimly lighted room. Some principle resembling Weber's law is necessary to account for this.

Measure of the Stimulus for Sensations of Sight. — The accurate measurement of visual sensations is complicated with the facts that the retina has a "light of its own," and that the laws of change in quality operate to obscure the laws of the change in quantity. Earlier experiments took the form of determining the distance to which a candle must be removed from an object in order that the shadow produced by its light might disappear in the shadow produced by another candle of like power but situated at a fixed near distance from the object. It was thus discovered that marked variations occur when we diminish considerably the light of the background on which the shadows are cast; and that the quotient which represents the least observable difference varies with the different intensities of the light employed.

Helmholtz and other late observers have used rotating disks with small black stripes upon their white surfaces ("Masson's Disks"). The grayish circles made by the admixture of the color of the stripes with that of the surfaces are then compared, as a test of the eye's sensitiveness to minute differences. The experiment may be varied by looking at these disks through gray glasses of varying intensity. In experimenting with color-tones the method may be used of comparing a white surface with one in which colored light has been mixed with the white.

The later experiments seem to show that the effect of background is enormous; and that the absolute strength of the stimulus used is also very important.

Weber's Law applied to Sensations of Sight. — The earlier experiments, conducted under the supervision of Fechner, were held to show that the law of Weber applies to sensations of light; and that the least observable difference, for absolute values of moderate intensity, is about $\frac{1}{100}$, — this being the smallest average difference in the brightness of the shadows which the eye can detect. But subsequent observations found the quotient to vary from $\frac{1}{63.6}$ for weak intensities of light to $\frac{1}{195}$ for stronger intensities. Helmholtz placed the medium value of the quotient of least observable difference at $\frac{1}{133}$: Aubert found a variation of from $\frac{1}{180}$ to $\frac{1}{120}$, even when not using absolute values of light above the middle of the scale of intensity. If care is taken to exclude disturbances from changes in the adjustment of the eye, from retinal exhaustion, reflection of the light from surrounding objects, etc., it seems probable that *Weber's law expresses the facts approximately well for sensations of light, when the strength of the stimulus is kept within the middle ranges of the scale of intensities.*

The same conclusion is apparently warranted with respect to sensations of color. The quotient of least observable difference is found to be different, however, for the different color-tones. Perfect agreement is not yet secured as to the nature of this difference: thus while one observer has adopted the quotients, $\frac{1}{14}$ for red, $\frac{1}{46}$ for yellow, $\frac{1}{59}$ for green, $\frac{1}{132}$ for blue, $\frac{1}{268}$ for violet, others make the sensitiveness of the eye greatest for changes in green rather than violet.

Lower Limit of Sensations of Light. — The least intensity of light which will produce any sensation at all was given by Aubert at $\frac{1}{300}$ of that reflected from white paper in the light of the full moon. Individual differences are here, however, so potent that all such calculations are very uncertain. There is, indeed, some evidence to show that certain persons are so extremely sensitive as to detect the presence of stimulus that lies far below the "threshold" of the average consciousness.

Quantity of Sensations of Taste. — It seems quite impossible to test by experiment the applicability of Weber's law to sensations of taste. The conditions under which the stimulus is applied, and its effect noted, are such as not to admit of giving scientific exactness to such experiment. The importance of individual idiosyncrasies in sensations of this sense is too well known to need mention.

Many experiments designed to fix the "lower limit" of the sensations of taste have yielded very interesting results. They show the astonishing tenuity of some forms of stimulus which will secure an appreciable effect in consciousness. The following facts are interesting as bearing on this point, rather than instructive as suggesting any law of the nervous system or of the mind.

Experiments in testing the effect of seven vegetable bitters on forty persons yielded these results: of salicine, 1 part in 12,000 parts of water was detectable; of morphine, 1 in 14,000; of quinine, 1 in 76,000 (some observers have claimed to detect 1 part in 1,000,000); of quassine, 1 in 9000; picro-toxine, 1 in 197,000; of aloine, 1 in 210,000; of strychnine, 1 in 826,000 (twelve tasters detected 1 part in 1,280,000).

The following table involves a comparison, with respect to sensitiveness of taste, between the males and the females experimented upon: —

Object tested.	Male observers.	Female observers.
Quinine	1 part in 392,000	456,000
Sugar (cane)	199	204
Acid (sulph.)	2,080	3,280
Soda (bicarb.)	98	126
Salt	2,240	1,980

In general, a smaller absolute quantity of stimulus, when in a relatively concentrated solution, will suffice to excite the end-organs of taste.

Quantity of Sensation of Smell.— The sense of smell has a great degree of "sharpness," or capacity for excitement by small quantities of stimulus, as distinguished from "fineness," or power to distinguish minute variations in the sensations. No experimental testing of the applicability of Weber's law to sensations of this sense seems practicable.

Incredibly small quantities of some substances will excite sensations of smell. One experimenter found that a current of air containing $\frac{1}{200000}$ of vapor of bromine excited a strong unpleasant sensation. Atmosphere polluted with $\frac{1}{1700000}$ of sulphuretted hydrogen could be detected. It was calculated that $\frac{1}{2000000}$ milligramme of musk was the least perceivable amount. A recent report is based upon experiments conducted by dissolving the smellable substances in alcohol, sprinkling them in an empty closed room with an atomizer, and mixing them with the air with a fan. It was thus found that a substance called "mercaptan" could be detected in volumetric proportion to the air of only 1 to 50,000,000,000. It was thus calculated that $\frac{1}{460000000}$ milligramme of this substance must excite sensation. The minuteness of this quantity may be faintly imagined when we remember that $\frac{1}{1400000}$ milligramme of soda is about as little as can be detected by the microscope.

On referring to what was said (p. 277 f.) of the value and significance of Weber's law we find our statements confirmed. Among the more cautious observers the conclusion has been forming itself as the result of years of experiment, involving thousands of cases, that the facts to which the law appeals can be summarized equally well in several formulæ; and that none of these formulæ hold good without many important exceptions. These exceptions have to do, in part at least, with laws of perception and judgment to which reference will subsequently be made.

Interpretation of Weber's Law. — Previous to experiment and scientific observation we should be inclined to suppose that the strength of the resulting sensation would vary in direct proportion to the strength of the stimulus. But we have seen that this is not so. The law proposed by Weber, and elaborated and defended by Fechner, holds that the sensations vary in quantity in an arithmetical proportion while the stimuli vary in a geometrical proportion. The so-called "law" turns out to be only one formula, which we may adopt in connection with others, to express the facts approximately for certain classes of the sensations when they have a moderate intensity, and when our estimate of them is undisturbed by conditions extraneous to their simple characteristic of quantity. How shall this law — or these formulæ — be interpreted? Three forms of explanation have been proposed in answer to this inquiry.

The *psycho-physical explanation* of Weber's law was adopted by its distinguished advocate, the physicist Fechner. This explanation insists upon making the law one of the widest application and highest import, as stating the relations between organic and spiritual activities. Fechner made the law, indeed, a basis for far-reaching philosophical speculation regarding the world of matter and mind. It need scarcely be said that we find absolutely no warrant for such a view.

The *physiological explanation* holds that the law of Weber applies to the relation between the stimulus, regarded as a mode of energy external to the body, and the amount of physiological action which it occasions in the nervous elements which it excites. The law may then be considered as one instance of a larger "neuro-physic" law which applies to all stimuli that diminish the excitability of the organism on which they act. Of this larger law the formula might run somewhat as follows: "The excitation caused by a change of intensity in a stimulus that diminishes excitability remains the same, if the relation of the change of intensity to the intensity on the basis of which the change is made remains the same." This rule holds good, however, only under similar conditions and within certain limits of absolute intensity of the stimulus. "Outside these limits . . . an increase of excitation occurs with small, and a decrease with great, intensity."

The *psychological explanation* of Weber's law resolves it into a special case under the greater law of the relativity of our inner states. In general, it may be said that *every mental state has its value determined*, both as respects its quality and its so-called quantity, *by its relation to other mental states.* It is the amount of change which mental apperception chiefly appreciates. Hence the important influence that attention, interest, habit, contrast, natural power of discrimination, etc., have upon those "estimates" on which we have to rely for a formula like that called Weber's law.

It seems to us undoubted that both the physiological and the psychological interpretation are necessary in order to understand the significance of whatever truth belongs to this celebrated so-called "law" of the relation between changes in the intensity of the stimulus and the resulting changes in the quantity of our estimated sensations.

CHAPTER XIII.

PERCEPTION BY THE SENSES.

THERE is a very wide difference between having sensations, however intense and complex, and knowing the qualities of things by use of the senses. Sensations, in themselves considered, are plainly psychical states; and, as such, they are devoid of a locality, or even an existence, external to the mind. But things are known as so-called objective or *extra*-mental existences; they are all, as we are wont to say, extended and related to one another "in space." Indeed, the one characteristic which things possess, as perceived by us, but which does not belong to the simple sensations which are the factors of the perceptions, is their *space-form.*

Now a study of the development of the mind shows indisputably that the perception of things does not come at once. We all have to learn to know things, — their space-qualities and spatial relations. As we shall see subsequently, it is not altogether out of the way to say that we have to learn to construct things perceived, in order to perceive them. The general problem which physiological psychology has to solve in this field of inquiry may, then, be stated as follows: *On the basis of what combinations of physical processes of sense do the different resulting sensations come to be combined into perceptions of things, under the new characteristic of space-form?*

In treating this branch of the subject, the method which we have, in the main, followed thus far, may profitably be reversed. It will make the whole of this difficult matter clearer if we give, first, a sketch of the general psychological theory of perception, and then speak, afterward, of particular forms of perception as illustrating the general theory.

GENERAL THEORY OF PERCEPTION BY THE SENSES.

The fact that perception by the senses implies such a very complex and long-continued evolution of the mind makes its scientific analysis both more difficult and more necessary. The ordinary operations of consciousness are wholly unable to do anything adequate toward making the requisite analysis.

"Common-sense" View of Perception Erroneous. — We cannot look on any complex object — for example, a landscape — without the conviction that we are immediately being impressed with a faithful *copy* of what exists wholly external to us, in reality. These *extra*-mental beings and the events which happen between them are, in the judgment of so-called "common-sense," quite enough to account for our perceptions. Indeed, they form the only necessary or possible explanation of these perceptions.

Scientific psychology shows that, strictly speaking, beings and happenings outside of our minds and bodies, in themselves, furnish no explanation whatever for our perceptions. They are and can be nothing to us, except as they *affect us*. They affect us only by action on the nervous system, — beginning with the end-organs of sense, continuing along the sensory nerve-tracts, and issuing in cerebral changes. But such induced activities of the nervous system are nothing *to us*, as minds, unless they are followed or accompanied by psychical changes. It is, indeed, only as necessary physical conditions of the psychical changes that they can be said to be either the explanation or the object of our perceptions.

Physiological View of Perception Inadequate. — But if the unscientific view of the nature of perception by the senses is illusory, the view of physiological science alone is inadequate. Indeed, the latter may be so represented as only to continue, in a more elaborate but indefensible form, the illusions of the ordinary impression. This, for example, is the case whenever the physical image formed on the retina is considered, in itself, to account for the mental perception of the visual object. The nervous processes which result from that orderly arrangement in the action of the stimulus upon the end-organs, which appears as a retinal image to the inspection of another observer, is indeed a necessary physical condition of our clear perception of the object. But the retinal image never becomes a kind of inner object for our own brain or mind. The same thing is true of the orderly arrangement of the excited elements in the cerebral substance itself. There is no brain-image, copied from the object, which the mind can immediately contemplate; and, if there were, we should need another eye connected with another brain to make use of it.

Neither does the accurate physiological description of the construction of the peripheral areas upon which the stimulus acts furnish, in itself, any reason for the perception of these areas as *in space*, or for distinguishing them from other areas nearer or more remote. To regard the mind as diffused through or over the surface of the skin, taking note — as it were — of the condition of this organ, or of the presence of the bodies with which it is in contact, is exceedingly crude and erroneous.

The Factors and Processes of Perception Psychological. — A true theory of the nature and growth of that knowledge of things which comes through the senses must always be distinctively *psychological*. For all the factors built, as it were, into the products which we call "perceptions" are mental; as we have already seen, these factors are sensations and sensation-complexes. The process of building, whether it be accomplished, for any object, more slowly or with what appears as a practical instantaneousness, is a mental process. The development of the capacity for this process is the result of a mental evolution. These truths must be admitted, from whatever point of view our study of perception is conducted. It is as necessary for physiological psychology to admit these truths as for psychology studied from the introspective point of view.

With these preliminary remarks, we enumerate the following considerations as necessary to any true theory of perception by the senses.

(1) **Synthesis of Sensations Necessary.** — In order to explain those steps by which the mere having of sensations issues in the perception of objects by the senses, we must assume that a combination of two or more qualitatively different series of sensation-complexes has taken place. This combination is sometimes spoken of as an "association" of sensations. But the word "association," on account of its established use to denote relations formed in time amongst different mental images, is not well suited to express the combination of sensations and sensation-complexes, with one another and with their memory-images, to form an object of sense. Such combination is rather of the nature of a chemical fusion (if we may borrow from physical processes and products a figure of speech), in which the factors lose their individuality, and the resulting compound product is determined by all the factors, without appearing to contain them. The word "synthesis" is selected to describe such a process of psychical uniting.

(2) **Spatial and Non-spatial Series of Sensations.** — Series of sensations which arise in the mind, on successive irritation of closely contiguous portions of the sense-organ, are fitted to enter into the process of "psychical synthesis."

Series of other sensations belonging to a different class of senses are not thus fitted. The former may be called "spatial series" of sensations; the latter, "non-spatial" series of sensations. Senses whose excitation gives rise to spatial series of sensations may be called "geometrical senses"; those that produce only non-spatial series of sensations may be called "non-geometrical senses."

For example: sensations of smell are obviously not fitted to form a so-called spatial series; indeed, they are incapable of being arranged in any series whatever. A being possessed of mere sensations of smell, without any of the tactile or muscular sensations which accompany those sensations in the case of man, would have — so to speak — no elements from which to construct *objects* of sense. The sense of smell is decidedly non-geometrical. On the contrary, we shall see that sensations of the eye and of the skin are of the "spatial-series" kind. These organs are the leading, and we believe — with the sensations of the muscles, joints, etc. — the only geometrical senses. By use of these senses we construct a world of objects having spatial qualities and set in relations of space.

(3) **Need of Local Signs.** — The locally different parts of the organs of the geometrical senses must each have some mental representative in the sensations which stimulation of each calls forth. As parts of the physical organism, they have no significance for the mind. Only the psychical changes which their irritation causes can become factors in the psychical products and processes of perception. The theory of perception seems then to demand the assumption that all sensation-complexes, which are to become factors of perception, must have a peculiar "local stamp," or shade, or mixture of quality, — dependent upon the place of the organ at which the stimulus is applied. This peculiar local stamp, or shade, or mixture of quality is called a "local sign." It is to the philosopher Lotze that

we owe the first elaborate theory of "local signs" and their relation to the formation of the perception of objects by the senses.

(4) **Stages of Perception.** — To perceive objects of sense is something which must be learned by every human mind. This is as true of objects near as of those remote; of the organs of our own body, as seen or felt by ourselves, as of the distant mountain or the fixed star. The end aimed at by nature, so to speak, is the clear and accurate construction of a "field of vision" and a "field of touch," by the two great geometrical senses. *Perception is then* — we can scarcely repeat or emphasize the declaration too much — *a mental achievement.*

In the one work of perception two particularly noteworthy stages are to be recorded. These are the "localization" and the "objectifying," or "eccentric projection," of the sensation-complexes. By the former we understand the transferrence of these sensation-complexes from mere psychical states to processes or conditions recognized as belonging to more or less definitely fixed points or areas of the extended body. By the latter we understand the giving to these sensation-complexes an "objective" existence, as qualities of objects (so-called "things"), situated within a field of space and in contact with, or more or less remotely distant from, the body.

(5) **Characteristics of the Spatial-series.** — In the process of perception by the senses, some of the many different sensation-complexes come to be localized as affections of the different parts of our own bodies; some of them also become projected — so to speak — outside of our bodies as qualities of things, either in contact with our bodies or situated at a distance from them. But not all kinds of sensation-complexes — it has been said — lend themselves to this kind of constructive treatment. Not all of them organize themselves into a world of independent

realities, spatially extended and spatially related. We inquire then, What characteristics must the series of sensation-complexes, arising through excitement of the organ of sense, possess in order to lend themselves to this synthesizing and organizing process?

Plainly it will not do to suppose that any two sensation-complexes, in order to combine in the construction of an object, must originate through the excitement of elements of the organ that actually lie side by side. The object perceived is indeed made up of parts contiguous in space. But the extension of the object perceived is never a copy of the extension of that nerve-expanse of the eye or skin, by irritation of whose minute parts the object is presented to the mind. For example, the nervous elements, on whose irritation the perception of an extended visual object depends, lie in the retinas of two eyes. Each retinal image is interrupted by the "blind-spot." The images have no value for perception unless the results of the irritation are propagated to the brain. In the brain, we know that the nervous elements, whose irritation results in the perception of the extended visual object, do not lie at all side by side after the exact manner of the parts of the object itself.

It is not necessary to perception that the nervous elements concerned in the production of the extended object shall themselves sustain certain spatial relations to each other. What is necessary is that the series of sensation-complexes which result from the irritation of these nervous elements shall be capable of definitely and reciprocally determining each other as series of sensations. To accomplish this, several characteristic qualities are necessary.

A. *Spatial-series of sensations must include sensations of similar quality that admit of easy, rapid, and frequent repetition in varying order of arrangement.* Senses which, like the eye and hand, have organs capable of rapid, precise, and nicely graded motion, are obviously equipped with that peripheral mechanism which is favorable to the production of spatial series of sensations. In the use of the eye, for example, there are produced various intermingling simple sensations of light and color-tones, together with muscular sensations of accommodation and of motion due to the action of the six muscles, and sensations of tactual sort as the eye rolls in its socket, etc. Moreover, these series of sensations thus evoked are capable of repetition; not only forward in the order of $\alpha, \beta, \gamma, \delta, \ldots \mu$, or in the reverse order of $\mu, \lambda, \kappa, \ldots \beta, \alpha$, but also in an endless variety or an interlacing network of fused sensation-complexes.

The same thing holds true of the series of sensations of light pressure, fused with factors derived from that unclassifiable crowd of other sensations located in the skin, as the hand moves over some object, or as an object is moved over some surface of the body. The same thing we believe to be also true of the muscular sensations, — though upon this point there is more reason for doubt and difference of view.

But obviously nothing similar can occur with the successive or fusing sensation-complexes of smell, or taste. Whatever series of such sensations we succeed in evoking in consciousness do *not* admit of "easy, frequent, and rapid repetition in varying order of arrangement."

The case of the ear, however, is sometimes contested. The question is raised: Why, if this view of the spatial-series of sensations be correct, should we not objectify the different tone-colors as lying side by side in superficial extension, or as having the three dimensions which belong to objects seen and touched? The objection implied in this question is not serious. In the first place, the ear is not, like the eye and the hand, a movable organ usable at will for the exploration of an object. Moreover, by far the greater number of the sensations it brings to us consist of sudden shocks of noise which occur to interrupt, as it were, the continuous flow of sensations of the eye, skin, and muscles. Sensations of musical tone, arranged in serial order, are relatively very rare. Few people have heard frequently more than a half-score of tunes. And even such series of sensations of sound do not shade into each other; or at all meet the conditions of the very point we are arguing, — viz., that of being adapted for easy, frequent, rapid, and varied repetition.

B. *Spatial series of sensations must be comparable and associable with each other.* In the use of the eye, graded series of sensations of color and light, with distinguishable differences of quality and quantity, are constantly accompanied by similarly graded series of tactual and muscular sensations. These different spatial series are comparable and associable with each other. The visual objects perceived are dependent upon such qualities as possessed by these series of sensation-complexes. So, too, the different series of sensations that arise from the simultaneous irritation of connected areas of muscle and skin possess the qualities necessary for the so-called "geometrical" senses. In particular, in forming the field of touch, the fact that the peripheral parts of the body so frequently come into contact with each other, is of great significance. Thus, two series of sensation-complexes corresponding to the perceptions of "touching" and "being touched" are, as it were, brought into *juxtaposition* in consciousness. This "juxtaposition" is not itself a spatial juxtaposition; but it is the necessary precondition of our forming the perception of the object as consisting of parts lying side by side.

C. *Spatial series of sensations must be differentiated by the possession of "local signs."* It has already been said that we understand by a "local sign," that peculiar mixture or shading of quality which belongs to sensations, otherwise qualitatively alike, on account of the particular locality of the organ to which the stimulus is applied. Lotze, the originator of the theory of local signs, conceived of them, in the special case of the eye, in the following way. In addition to the same sensation (for example, red, R) which each color-tone produces at all places of the retina, it produces also an "adjunct" or "accessory" impression, α, β, γ, etc., for each of the different retinal places, a, b, c, etc. The nature of this adjunct impression for the different places of the retina he explained as follows: When the image of a luminous point falls upon any place of the retina lying outside of the "clear-spot" of vision, we instinctively rotate the eye in order to bring this image upon the most sensitive spot of the retina. Thus a series of changing "feelings of position" have been developed, corresponding to each arc through which the eye has been frequently rotated. To fixate the point E, rotation has taken place frequently through arcs corresponding to PE, RE, SE, etc. To these arcs of rotation correspond the "feelings of position," $\pi\epsilon$, $\rho\epsilon$, $\sigma\epsilon$, etc.

Now when two or more points of the retina, lying in different directions, are simultaneously stimulated, — for example, P, R, S, — this calls into consciousness at the same time all the "feelings of position" corresponding to the arc of rotation of each point.

Objections may be raised to Lotze's view of the nature of the so-called "local signs" of the eye. Especially does the term "adjunct" or "accessory" impression seem to us unfortunate. Nor are we perfectly sure that the excited retinal elements do not, of themselves and irrespective of previous movements of the whole eye, have a peculiar value in consciousness. But the assumption, that the different minutest distinguishable areas of the eye and skin have attached to their action peculiar shadings in the resulting qualities of the sensations evoked, seems required for the construction of any intelligible theory of perception. Moreover — as we shall see subsequently more in detail — the same assumption also seems warranted by the facts.

In general, then, we conceive of the local signs in the following way: The irritation of the different elements of certain organs of sense gives rise to sensations which differ in the shading of their quality, according to the locality in the organ at which the elements are situated. But, especially in our ordinary experience, the irritation of none of these elements takes place singly. The simultaneous irritation of several of these elements results then in a "sensation-complex"; and this sensation-complex is distinguished from all other most nearly similar sensation-complexes, by a peculiar mixture of shades of quality dependent upon the number and local character and relation of all the elements thus simultaneously irritated.

For example, the sensation-complex aroused by irritating together the retinal elements *a*, *b*, *c*, *d*, etc., differs from that aroused by irritating the retinal elements *b*, *c*, *d*, *e*, etc. The same thing holds true of locally related nervous elements of the skin. Indeed, each of the spatial series of sensations is characterized by a kind of local coloring for its different sensation-complexes.

The foregoing theory is, therefore, opposed to that of Bain and others of the so-called Associational School, who endeavor to reduce all local signs to mere symbols of associated differences in the muscular sense. We shall see abundant reason for holding that the muscular sense has by no means such an exclusive position as the theory of this school would indicate.

One other important consideration remains. The local signs of the different spatial series evoked in the use of a very complex and active organ, like the eye or the hand, must necessarily modify each other. Hence there arise admixtures of sensations dependent upon the fusion of the specific energies of the nervous elements simultaneously excited. For example, the place where we locate a visual object does not depend merely upon the place where its image falls upon the retina; but also upon the "feelings of position" which indicate to us the amount and direction of the turning of the eye, and even of the head, neck, and trunk of the body. Thus, too, is our perception of the position, size, shape, etc., of any object, when located in contact with the skin, dependent upon a gross mixture of many delicately variable sensation-complexes belonging to various spatial series. The complication and elaborateness of experience, and the niceness and variety of discriminations, which this theory implies, will be no obstacle to any student of the mind who has carefully observed and reflected upon the phenomena.

Indeed, we may observe our own sensations in a way which seems to give the warrant of immediate intuition to the view which regards them as infinitely varied in local coloring. Let one select two portions of the body whose structure and function are most nearly identical; and then compare the sensation-complexes called out by simultaneously irritating these portions. The corresponding areas on the tips of the two middle fingers will fulfil the necessary conditions. When we gently rub these finger-tips together (but only in case neither is too widely differenced from the other by some peculiarity of structure or use,—*e.g.* by a callous spot or something similar), the sensation-complexes corresponding to the terms "touching" and "being touched" seem to *fluctuate between the two fingers.* Either finger, accordingly, can at will be regarded as touching or as being touched. Or, perhaps, the whole sensuous condition evoked almost entirely loses its objective reference, and seems to resemble the purely subjective character of smells or sensations of musical tone.

Under ordinary circumstances, however, the two sets of spatial series evoked by bringing two areas of our own bodies into contact are so strongly characterized by the local signs belonging to each, that we have no choice as to which member shall be regarded as touching, and which as being touched. For example, if the forehead be moved against the stationary tip of a finger, the character of the sensation-complexes will deceive us into attributing motion to the finger rather than to the forehead. The tip of a finger of normal sensitiveness in contact with the tip of a callous finger is determined as the one touching something; the callous finger is determined as a part of our body, being touched. Pricks, hard pressure, pains, sensations of creeping and tickling, we locate *in* the body. Indurated spots of our own skin we regard as *foreign* substances. In general, sensations characterized by local signs which have a strong and decided tone favor the process of localizing; sensations of a toneless kind favor the process of objectifying.

(6) **"Empiristic" and "Nativistic" Theories.**—Two rival views exist as to the explanation of the nature and origin of perception by the senses. They have been called the "nativistic" (or intuitional) and the "empiristic" by Helmholtz, and the "nativistic" and "genetic" by Wundt. These different views can scarcely be spoken of as opposed theories; they are better described as the result of tendencies which appear in the attitudes assumed by two classes of observers towards two classes of facts and towards the explanation of the facts. Adherents of the "nativistic" view are inclined to depreciate the explanations offered by the empiricists, as to how and why our perceptions come to have the character they actually bear; they themselves prefer to emphasize the intuitional and underived activity

of the mind. But adherents of the "empiristic" view, on the contrary, are inclined to admit no explanations which refer to the mind's native constitution or powers; they prefer to fill in the gaps of knowledge with explanations derived by conjecture from alleged experimental data.

We believe that certain principles, contended for by both these theories, must be admitted. The right to "explain" mental phenomena, by giving the descriptive history of their rise and development, and by scientific statement of the relations they uniformly sustain to each other and to phenomena of a physical order, is, of course, beyond question. It is for this right that the "empiristic" school contend. In concession to this view it must be admitted that the "immediateness" or intuitional character of all our perceptions is illusory. This is as true of the art of seeing and touching common things, as it is of the art of handling a graver's tool or of playing upon a violin.

On the other hand, the "empiristic" theory can never so far perfect its explanations as rightfully to withhold from the mind, considered as the subject of the psychical phenomena, the claim to possess all its so-called *native* powers. The elements of perception are psychical factors, —sensations and sensation-complexes; they must, therefore, be regarded as forms of the mind's reaction on occasion of the stimulation of the nervous centres in definite ways. The laws of the synthesis and evolution of the perception-products and perception-processes are mental laws, — that is, constitutional and native modes of the behavior of the subject which we call mind. Especially is it true of this characteristic of "space-form," which belongs to all the complex products of perception by the senses, that it is a subjective and mental mode of arranging and regarding the sensation-complexes. *Space-form is mental form; to impart it is a mental achievement which implies a native character to the mind.*

In making such admissions as those immediately foregoing, it is implied that we have reached the limits of scientific explanation by tracing the genesis and uniform relations of the phenomena. But such limits are met in all attempts at scientific explanation. They are not, indeed, to be arbitrarily set up, nor held fixed in place at points beyond which scientific research has succeeded in passing. But their existence is to be acknowledged in every form of science.

Our general position will subsequently receive special illustration in the case of the eye. It is over the theory of perception by this organ that the "nativistic" and the "empiristic" views are most warmly debated. Some investigators conclude that perception of "extensity" in three dimensions is *native* to the eye. Others would limit this native power of the eye to the perception of extension in two dimensions. Others still take the more purely "empiristic" position and contend that the original sensation-complexes of a visual order have *no* spatial qualities; they are to be regarded as neither "out" nor "spread-out,"—whether in two or three dimensions. Yet the most extreme "empiristic" position cannot avoid virtually ascribing to the mind the native power to have and to combine the sensation-complexes, in such order and manner, that the perception of objects in three space-dimensions is the actual result of its activity.

The theory which we shall now illustrate involves the following position on this point: *Perception is an achievement due to extremely complex activities of the psychical subject — the Mind; it involves the synthesis of a number of sense-data according to laws that are not deducible from the nature of the external objects, or of the physiological action of the end-organs and central organs of sense.* What are the laws, or uniform modes of action, followed in the genesis and development of perception by the senses, has already been somewhat fully stated. The subsequent treatment of the particular senses will explain and illustrate them more fully. It will also add to them a number of subordinate laws; and it will indicate how far, in each case, the "empiristic" and the "nativistic" views are capable of scientific verification.

It must constantly be borne in mind that the scientific position, as psychology takes and maintains it, regards the nature and evolution of perception as a subjective affair. It discards, at once and for all, the so-called "common-sense" point of view, from which the perceptions are regarded as "copies" or "impressions" of things having a ready-made and *extra*-mental existence. Neither is its point of view the same as that of purely physical or physiological science. In other words, we investigate the genesis and development of *perceptions*, not the constitution and growth of material *things*. But since we are considering psychology from the physiological point of view, we regard this genesis and development of perceptions as determined by, and conditioned upon, the activity of the nervous system when excited by external stimuli.

PERCEPTION BY THE "NON-GEOMETRICAL" SENSES.

A certain measure of perceptive knowledge of things comes to us indirectly through those senses which have been called "non-geometrical." Strictly speaking, the knowledge thus gained never becomes an immediate perception of things. The rather does it always remain an indirect knowledge *about* things; but about things which we perceive directly through the "geometrical" senses so-called.

Perceptions of Smell. — The perceptions of this sense differ only as respects fineness, duration, and accompanying tone of feeling; they have neither size nor shape, nor spatial properties of any kind. They are not, as sensation-complexes purely of smell, directly localized. They are indirectly localized, however, in the nose and surrounding parts of the face, by the tactual and muscular sensations which accompany them.

The exploits of some animals give ground for the conjecture that every species, and probably every individual animal, has an odor of its own. From our own experience we know that different smellable objects produce characteristic sensations of smell. In this indirect way we are said to *perceive* the object in whose effluvia the irritation of our end-organs originates. Its distance and direction are known by the variations in intensity and quality of the sensations, particularly as we turn the head, and as we advance or recede in one direction or another. In case of simultaneous influence from two smells, the stronger overwhelms the weaker. We cannot hold these sensations side by side, as it were, even by means of the tactual and muscular data with which they are connected.

Perceptions of Taste. — Since the tongue is the chief organ of touch, and is very mobile and sensitive to pressure, sensations of taste are closely connected with those of touch. In themselves considered they have no spatial qualities, no local habitation.

When a sour mass is laid on one half, and a bitter mass on the other half, of the tongue, a conflict of sensations takes place. We may determine this conflict, under certain circumstances, by choice; but we cannot place the two conflicting sensations side by side in consciousness. When certain tastes compensate each other — as, for example, when the sugar neutralizes the acid of the lemon — it is probable that the compounding of the two effects takes place in the brain. The sensation of bitter is particularly difficult to cover or neutralize.

Perceptions of Hearing. — We know that we hear *with* the ear, chiefly through those sensations of shock to the muscles and skin of the region which are produced by loud and massive or piercing sounds. Certain acoustic sensations called "entotic" originate through excitement within or near the organ itself; the stimuli of these sensations are probably, in most cases, transmitted through the tympanum. Thus a low musical tone, due to the vibration of the adjoining muscles, may be heard by pressing the fingers in the ears and setting the teeth tightly together. Yawning may produce a cackling noise; quinine and other cerebral excitants induce ringing or singing in the ears. The beating of the heart and the whirring of the blood are often audible. The localization of "entotic" sounds is always an elaborate act of judgment, and is often extremely perplexing. In certain pathological cases the power to distinguish between them and external sounds is wholly lost.

We orientate ourselves in space, with reference to external sounds, as an acquired art, differing greatly in different individuals and dependent upon previous experience in the use of the senses of sight and touch. The data on which these judgments are founded are only partially explored. It appears that the sensitiveness of the skin of the external meatus and of the tympanum, as well as the position and normal direction of the semi-circular canals, are involved. Some patients with anæsthesia of the skin, extending to the meatus and tympanum, can hear perfectly well the tick of a watch, but cannot tell on which side of the head to place it or whether the sound is external to the head or not. Recent experiments tend to show that possibly the nerves of each ampulla have a specific energy in localization. With normal ears, right and left are rarely confused; but positions where the angle made by the direction of the sound with the plane of two canals is nearly equal are easily confused. Years ago Rayleigh found that the direction of a tuning-fork could be much better detected, when held to the right or to the left of the head than when held either behind or before.

Our perceptions of the absolute distance of sounding objects are entirely dependent upon our knowledge of the quantity and quality of the sounds ordinarily proceeding from them. It may be that a change in timbre aids our perception of the distance of a musical "clang."

Sensations of sound appear, therefore, not to be directly localized, but to be projected, through complicated indirect inferences, in a space constructed by the activity of the eye and the hand. The utmost that could be claimed would be that the "sensations of position" originating in the semi-circular canals have become so fused with certain acoustic sensations as to constitute a kind of tact which has the semblance of intuitive perception. Even this fusion, however, we believe to be an acquirement dependent upon our perceptions of things by the geometrical senses. Hearing, then, belongs among the non-geometrical senses.

CONSTRUCTION AND USE OF THE FIELD OF TOUCH.

Every account of the process by which a *Field of Touch* is constructed, and extended objects become known as in contact with the skin at definite points or areas, must begin by describing the data which the mind has for such activity.

Fineness of the Skin's Sense of Locality. — The physiologist E. H. Weber first established a rule for measuring accurately the fineness with which different areas of the skin are able to localize objects in contact with them. For this purpose he made use of the two points of a compass, blunted so as to prevent the sensation of being pricked. The minimum distance at which these two points, when applied to any area, could be felt as *two* localized sensations, was the measure of the sensitiveness of that area. This distance he found to vary from about 1 millimeter for the tip of the tongue, 2 for the volar side of the last phalanx of the finger, 5 for the red part of the lips, and 11 for the cheek, to 31 for the back part of the hand, 40 for the forearm, and 68 for the skin of the middle of the back, and of the upper arm and leg. A recent investigation with the same means for measurement has employed the "method of equivalents," — that is, the compass points were placed 4 or more lines (1 line = 2.256 mm.) apart on the forehead; and it was then found how far apart the points of a second compass must be, on the various areas of the body, to give a sensation of equal aperture. The numbers of the table are given in ratios of the parts compared.

CONSTANT DISTANCES.	FOREHEAD TO LIP.	FOREHEAD TO WRIST.	PALM TO FOREHEAD.	PALM TO FOREHEAD.	MEAN OF THE LAST TWO.	CONSTANT DISTANCES.	FOREHEAD TO FINGER-TIP.
4 lines	1.668	1.0165	0.972			0.5	1.051
8 "	1.353	0.9763	1.043	0.982	1.012	1.0	1.055
12 "			1.048	0.996	1.022	1.5	1.044
16 "			1.037	0.989	1.013	2.0	1.033
20 "			1.016	0.985	1.000	2.5	1.028
24 "			1.032	1.003	1.017	3.0	1.025

Character of the "Sensation-circles." — The areas on the surface of the skin within which the foregoing minimum distances of the points of the compass are felt as two, are called "Sensation-circles." They have, as a rule, an elliptical shape with their long axes up and down. Their variation may be shown by the following experiment: Separate the points of the compass just a little less than is necessary for their being felt as two when applied to some particular area (say the cheek) and then cause them to travel slowly, without changing their aperture, over other areas, — the person experimented upon being blindfolded.

The points will appear in consciousness to separate more and more as the more sensitive areas are traversed; and they will appear to come nearer together again as the less sensitive areas are traversed. The sensitiveness of the different areas is in inverse proportion to the size of the sensation-circles.

The same principle holds when the entire area of the sensation-circles is filled up so as to make a *continuum* of localized sensations. Thus Weber found that the circular form of a tube of 1½ Parisian line in diameter could be recognized by pressure on the tip of the tongue; while on the skin of the abdomen the diameter of the tube must reach 3¾ inch before its form was recognizable. The same thing can be shown by laying rods on the skin.

Great differences exist between different individuals with respect to the sense of locality on corresponding areas of the skin. Some are not more than one-fourth as sensitive as others. This sense is also capable of rapid cultivation. In a few hours the perceptive power of some areas can be more than doubled. Such growth in power is slower at first for the areas not in ordinary use; it is more rapid for those accustomed to daily use. It is a very surprising discovery that practice, exclusively with a member of the body on one side, will result in improving the corresponding member of the other side. Thus Volkmann reduced the minimum perceivable distance with the tip of the finger on *both* hands — on the right from 0.85 to 0.4, and on the left from 0.75 to 0.45 line — by practising exclusively with the *left* finger.

The high degree of fineness for certain space-perceptions attained by some blind persons is well known. With those of normal vision some parts of the body, especially the tips of the fingers, are capable of receiving great refinement of cultivation. But one experimenter failed, even by persistent education for an entire month, to reduce the obtuseness of the skin of the back more than by about one-fourth.

Explanation of the "Sensation-circles" of the Skin. — The reason for this marked difference among the different areas in the general field of touch is both physiological and psychological. The physiological reason is not, however, very clear. It was natural at first to assume that each circle is provided with one nerve-fibre only, whose terminal expansion covers the entire circle. But every point within each circle is itself sensitive, and the circle as a whole may be diminished greatly by the effect of practice. Such an explanation, therefore, will not hold. Weber himself thought that the sensation-circles all contain a number of isolated nerve-fibres; and that, in order to have the impression of two distinct localized sensations, several unexcited fibres must exist between the two excited fibres.

The psychological explanation of the sensation-circles of the skin accords with the principles already laid down for all perception by the senses; it therefore illustrates and proves those principles. These circles represent the spatial difference between the points at which stimulus must be applied to the skin in order that the difference in the "local coloring" of the different resulting sensations may be "just observable." The "local signs" of the skin are complex mixtures of sensations belonging to the different localities. As such they are dependent, not only upon unchanging anatomical and physiological differences, but also upon habit and upon association with each other and with other spatial series of sensations belonging to the same organ.

More precise description of the causes why the sensation-circles — or, what is the same thing, why the degrees of the fineness of local perception — differ so greatly for different parts of the body's surface, would include the following particulars. The skin of the different areas varies with respect to richness in nerve-fibres, thinness, and so sensitiveness to light pressure, and character of the support and tension it receives from the underlying parts of fat, muscle, tendon, and bone, when stretched across them. The relative fineness of the organ's sense of locality is also a function of its mobility. Thus, in general, the power of localization belonging to the different parts of the arm, from the shoulder-joint to the finger-tips, increases in some such proportion as the movableness of its different parts.

The view to be taken of the nature of Weber's "sensation-circles" has been largely changed by the recent experiments — already reported (see p. 237 f.) — of Goldscheider and others. The fineness of discrimination possible for any area of the skin depends largely upon how all the points irritated stand related to the specific "pressure-spots" within that area. Only when two irritating points touch two pressure-spots are they *felt* as two. The impression of being doubly touched may be excited by the points of the compass when lying much nearer together, if the pressure-spots upon which they rest belong to two different chains than if both spots belong to the same chain. The minimum distance which admits of perception is surprisingly reduced by selecting pressure-spots which have a first rate of intensity; that is, from which the chain of such spots radiates, or at which it makes a sharp bend. How much the table of least observable differences can be reduced by careful experimenting under this rule, a comparison of the following figures with those given by Weber (see p. 308 f.) will show: —

Part of the body.	mm.	Part of the body.	mm.
Back	4–6	Back of hand	0.3–0.6
Breast	0.8	1 and 2 phalanges (volar)	0.2–0.4
Forehead	0.5–1.0	1 and 2 phalanges (dorsal),	0.4–0.8
Cheek	0.4–0.6	Upper leg	3.0
Nose and chin	0.3	Lower leg	0.8–2.0
Upper and lower arm	0.5–1.0	Back, and sole of foot	0.8–1.0

When an area of the skin is touched with any object, even so small as the blunted points of the compass, a large number of pressure-spots, and of other spots of specifically different sensations, are simultaneously excited. The result is a very tangled complex of sensations fused into a sensation-complex, having its own peculiar local coloring. Sensations of pressure are primarily "punctiform"; it is only as they are massed, and fused with other sensations, that perception of a tactual *continuum* results.

The ultimate explanation of the "sensation-circles" of the skin, as regarded in the light of the most modern researches, forcefully illustrates and confirms the theory of perception by the senses which was stated in general form at the beginning of the present chapter.

The *construction of the field of touch*, in the most general meaning of the words, is closely connected with the rise and growth of another form of perception; we refer to —

Perception of Motion by the Skin. — Different parts of the surface of the body differ greatly with respect to their power of discriminating the fact, the direction, and the amount of motion in contact with them. Specific "sensations of motion" are referred to by some writers on this subject. We believe the language to be misleading. *Perception* of motion depends upon the successive irritation of the organ in such manner that the local coloring of the resulting sensation-complexes is changed with the right degree of rapidity. These sensation-complexes fade into each other, as it were, after a manner analogous to that of the fields of vision when we slowly turn a kaleidoscope before the eye.

The discriminative sensibility of the skin for motion is much greater than that for separate touch as determined by Weber's experiments. It does not, however, seem too great to be accounted for by changes in local coloring as possible in accordance with the more recent experiments.

G. Stanley Hall found the average distance, in millimeters, which a metallic point could move over the skin at a rate of 2 mm. per second, before a judgment of direction could be securely formed, — as follows: forehead, 0.20; upper arm, 0.40; fore-arm, 0.44; skin, 0.60; palm, 0.74; back, 0.85.

Motion of a point travelling over the skin can be produced so slowly as not to be perceived at all, even after two or three inches have been actually traversed. Heavy weights moving at the same rate of motion as light weights seem to move faster. The heat-spots and cold-spots are probably of service in judging the rate and direction of motion. The same thing is true of sensations of deep pressure, when called forth in combination with those of light touch.

Conclusions from the foregoing data agree admirably with the several points in the general theory of perception which have already been proposed. Our perception of moving bodies is especially keen because the motion does not simply multiply, but also *diversifies* our data for filling up the dermal blind-spots, and so judging the nature of impressions. The perception of each locality may be described as based upon a "tangle" of various dermal sensations; for the dermal "local signs" are complex mixtures of sensations, which give to each locality a characteristic local stamp. Our ability to perceive the rate and direction of motion over the skin depends upon the degree, quality-mixture, and rate, of the changes of these sensation-complexes.

Localization of Temperature-Sensations. — In all our ordinary perceptions constructive of the field of touch, sensations of temperature are combined with those of light pressure or of motion. Recent experiments show that the minimum distance apart at which two cold-spots or heat-spots can be *felt as two*, differs greatly for the different areas of the body. The following table gives the results of Goldscheider's experiments, in millimeters: —

PART OF THE BODY EXPERIMENTED WITH.	COLD-SPOTS.	HEAT-SPOTS.
Forehead, cheek, and chin	0.8	3–5
Breast	2.0	4–5
Abdomen	1–2	4–6
Back	1.5–2.0	4–6
Upper arm	1.5–2.0	2–3
Lower arm	2–3	2–3
Hollow of the hand	0.8	2.0
Back of the hand, and upper and lower leg	2–3	3–4

It will be seen that the sense of locality connected with the cold-spots is about twice as fine, as a rule, as that connected with the heat-spots. Although the temperature-sensations, by constituting a part of the "local mixture," probably aid in the perception of spatial relations by the skin, they are not well fitted in themselves to constitute a so-called "spatial series." Whenever, for example, any area of the skin is stimulated by both heat and cold simultaneously, and at points too near together to be discriminated by touch, the two sensations are not localized as lying side by side. The area, on the contrary, feels as though it were being touched alternately with a hot and a cold object; that is, a wavering of perception takes place similar to that which takes place in a so-called "strife of color-sensations." Moreover, if we bring together two large areas of the skin, that differ considerably in temperature, it is difficult by strict attention to the temperature-sensations alone, to tell which area is the warm one and which the cool.

ORIENTATION OF THE BODY IN SPACE, WITHOUT SIGHT.

How our perceptions — or "feelings," as they are sometimes called — of the position of our own bodies, either as wholes or with respect to the relations of the different members, are connected with the dermal sensations, has been much debated. That the sensation-complexes which have just been described, and which are localized in the skin, are of great assistance in forming these perceptions, there can be no doubt. Patients afflicted with anæsthesia of the skin have great difficulty in telling, with the eyes closed, in what positions the limbs, thus insensitive, have been passively placed. For example, we are told of one such patient that, "with an arm elevated by a weight and pulley, and being told to touch his knee, he felt for it about his shoulders."

A survey of the entire subject, however, convinces us that it is not by sensations originating in the skin alone that we orientate in space our bodies, whether as wholes or with respect to their separate members, excluding the guidance of perceptions of sight. In such a work of orientation, the perception of the position of the limbs through sensations arising in the conditions of *the joints*, undoubtedly plays an important part. Slow movements of the limbs with short excursions can sometimes be recognized by anæsthetic patients, when accompanied by pressure on the joints; otherwise not. Passive movements of the fingers, or other members, are less easily recognized when the joints have been rendered insensitive by the faradic current.

In addition to sensations of the skin and joints, two other classes of sensations have much to do with the perception of the space-relations of our bodies, — excluding sight.

Perceptions of the Muscular Sense. — Three views have been held as to the character and service in perception of those sensations which are attributed to the muscles of the body. One of these views denies that specifically *muscular* sensations exist; the sensations that go by this name it attributes to the skin as influenced by the changes of tension in it, when the underlying muscles are moved. Another view (that of Wundt) resolves these sensations, so far as they are not tactual, into "central feelings of innervation," which differ only in intensity, and not in specific quality, and which result from changes, initiating movement of the body and its members, that take place in the brain as correlated with acts of will. The third view (which we advocate for reasons already referred to in part) maintains the existence of muscular sensations as important factors in those "spatial series" of sensations whose data are necessary for our perception of the changing relations of our body and its members, to one another and to other objects, in space.

It has already been said (p. 242), we may derive a certain support for this view from an appeal to consciousness. In moving any limb, or in changing the posture of the entire body, attention enables us in a measure to separate from the sensation-complexes of the skin and joints, other changes in sensation which we localize in the deeper parts of the flesh. As the circuit of motion gone through by any limb increases, or the intensity of the strain upon the muscles becomes greater, the quality of the *mass* of resulting muscular sensations is perpetually changing. Every one who has called, by unusual exercise, upon the unused and more deeply lying muscles of the body, knows what *surprises* (consisting of qualitatively *new* masses of sensations, as it were) are the resulting response of consciousness.

Moreover, experiment and pathology tend to confirm the impression derived from attention to the phenomena of consciousness. They show that the power of perceiving the position and movement of the body and its members does not vary directly and solely as the sensitiveness of the skin and joints. The superior discriminating power which any limb acquires, as soon as it is permitted to move over the object, and to explore it with the moving limb, is due to the series of muscular sensations thus evoked. When, for example, we trace, with the same spot of the fore-finger, and with eyes closed, the outline of an unknown object, it is the direction and amount of motion of the arm, as known by the series of muscular sensations, which is chiefly helpful in constituting this series of perceptions. In all active touch, whether over small or large areas of body, however, this series of muscular sensations constitutes, with the dermal sensations, a sort of double system of local signs. Hence, as the experiments of Hall and others show, our judgment of the direction of motion, even when the body is itself motionless, is prompter, if the weight resting on the skin and moving is increased up to the limit when other disturbing sensations intervene. Recent experiments seem also to show that, in estimating the weight of bodies lifted, when they cannot be seen, the judgment is much influenced by *the speed with which the weight comes up.* If the motor discharge, which is calculated to be adjusted to the raising of any particular weight, meets with unexpectedly little or unexpectedly great resistance, and the weight rises with unaccustomed velocity, very singular illusions may result. Of course, our perception of the speed with which the weight rises is complex, and depends upon a variety of peripherally arising sensations.

Perception by the Semi-circular Canals. — Recent experiments seem to settle beyond doubt the influence of sensations originating in irritation of the semi-circular canals upon the sense of direction, — at least, in the case of some animals. All three canals have now been separately excited by the electrical current, and the direction of the resulting motion seems to be specific for each one of the three. It is highly probable that these same organs in man are closely connected with the perceptions by which he fixes the position and motion of his body and of its members in space. Precisely what is the character and the amount of this influence physiological psychology is not as yet in a position to affirm.

We cannot proceed much farther in this direction for the confirmation and illustration of the general theory of perception, without introducing the case of the eye. But it is probable that in orientating ourselves with closed eyes, whether we remain at rest or are in motion, an important difference exists between what have been called the "*static*" and the "*dynamic*" perceptions and illusions. When, for example, the head is twisted to one side, with closed eyes, the errors in our attempt to localize are such as to show that "*static* sensations of direction" come through the muscles of the eyes. On the other hand, the so-called *dynamic* sensations produced by rotating the body are largely due to variations in the endolymph pressure, as the head is turned around its various axes.

Indeed, the knowledge of the positions of our bodies and their members, even as gained without perceptions of sight, is a very complicated affair. It depends on several kinds of dermal sensations, on sensations of the joints, tendons, etc., on muscular sensations, and on sensations of general sensibility appreciating the gravitation of fluids and the relation of internal organs of the body.

In the development of this kind of knowledge, the activity of the hand, as it moves over or lies upon the various surfaces of the body, is especially important. It constantly carries with it, as it were, the two great series of combining and separating and re-combining sensation-complexes of the spatial order, — namely, sensation-complexes of the skin and those of the muscles.

The localization of certain fixed and characteristic parts of the general area of the body, that have marked local characteristics and frequently recur in experience, is a prime achievement in the construction and use of the field of touch. To these landmarks, as it were, other points or areas, subsequently discovered, are referred. One hand learns to know the other; the right hand chiefly explores the left arm and side and the upper right leg; the left hand, the right arm and side and upper left leg. The finger-tips, especially of the right hand (and, in the infant's case, the lips), have an office to perform similar to that of the retina: they are the centre, or hearth, of clear perceptions of touch. But in order to bring them to their object they must be moved: through this motion fresh combinations of muscular and tactual sensations result. In marked contrast with these active and discriminating organs of the body stand certain parts of the surface which are known to us at all only as they are clumsily excited to undiscriminating responses by the pressure of our clothing or of the burdens temporarily in contact with them.

But long before the field of touch has been constructed with any considerable approach to completeness, the eye has already explored those parts of the body which are open to its inspection. It learns first to know the hand, which nature keeps constantly in motion before it. As objects excite tactual sensations by resting on the hand, or muscular sensations by being handled, the eye is also active in such a way as to combine these two classes of sensations with visual sensation-complexes. Very early in the development of the perceptive power, it comes to be the leader and critic of the discriminations connected with most of the tactual and muscular sensations. Its power of rapid movement over the whole field, its delicate judgment on account of the finely shaded complex local signs, which its activity calls forth, give it a marked superiority as a "geometrical" sense. For this reason, one born blind can never attain the same "comprehensive simultaneousness" for his perceptions of the spatial relations and spatial qualities of his own body or of other objects.

Among the interesting complex perceptions which result from the habitual synthesis of dermal and muscular sensation-complexes, are the so-called —

"Feelings of Double Contact." — It is by means of these perceptions that, exclusive of the influence of sight, skill is acquired in the use of tools, weapons, and musical instruments. In such cases, the process of eccentric projection (coupled with localization) goes so far that we feel the object with which the implement is in contact, not so much in the hand as in the implement itself, as though it were actually a part of our sentient organism. The wood-carver feels his chisel move through the stuff he is shaping. He guides it as unerringly as the violinist guides his finger, so as to lay the tool, with a given degree of pressure upon a given spot. Such management is, of course, made possible only by delicate changes in the local coloring of the tactual and muscular sensation-complexes, as the movement of the handle of the tool, in and with the hand, is variably related to the surface of the skin and underlying muscles.

Perceptions of this sort are attained through a more artificial and elaborate process of localization. As skill grows, they become perceptions of the texture or condition of a comparatively remote external object, *through* an organ or instrument, instead of perceptions of the condition of our own bodily members. The relation of these "feelings of double contact" to our estimate of our own personality, to our pleasure in extending the sphere of the mind, as it were, has been discussed by Lotze in an interesting way.

CHAPTER XIV.

PERCEPTION BY THE SENSES.—Continued.

THE most wonderful and complex of all the organs of perception is the human eye. Nature has equipped it with superior means for furnishing to the mind a variety of data, as respects both quantity and quality, for the nicest discriminations. It reaches a very high degree of psychical development very early in life. For these and other reasons it is peculiarly difficult to give a complete and satisfactory account of those sensation-complexes which originate through its activity, and of the laws of their combination and elaborating. No less than eight different data, or *motifs*, are assigned by one authority, as used in adult monocular vision for the perception of the third dimension of space. In stereoscopic vision with both eyes in motion, at least two other very complicated series of sensations, of "spatial" character, must be added to this number.

The Empiristic and the Nativistic theories of perception find their principal grounds of contention over the case of the eye. The questions about which they contend may be essentially reduced to this: How, and at what stage in the development of perception by the eye, do the visual sensations attain the so-called quality of "extensity" (or bigness), as distinguished from intensity and color-tone? Several of the data enumerated in the above-mentioned ten classes, are of only secondary rank and value. Thus much, however, seems necessary to the most elementary form of visual perception: *Sensations of light and color, differing in* *intensity and quality, but simultaneously present in consciousness, must be systematically ordered by the help of local signs of the retina, and associated with other spatial series of muscular sensations arising from accommodation of the eye and from its motion.*

The Two Eyes as One Organ. — The complexity of the combinations arising in the case of the eye is, of course, greatly increased by the fact that there are *two* eyes acting as *one* organ. Thus there are two sets of certain data to consider: for example, two systems of retinal signs; two images of each object; two sets of motion in accommodation, and in convergence and divergence of the axes. The two eyes are, however, one organ of vision in such a sense that, even when one eye is closed, the perceptions of the open eye are irresistibly influenced by sensations originating in the condition and action of the closed eye. The two eyes act separately in such manner that they are not one organ as the two nostrils or two ears are one; but they act together in such manner that they are more truly one organ than are the two hands. We shall have frequent occasion to notice gaps or errors in certain theories of perception, which are occasioned by neglecting the influence of one of the two members of this double organ of vision.

Method of Discussion to be followed. — It is not possible to trace the development of visual perception by an appeal to memory or imagination. Neither are the experimental data sufficient to fill up all the gaps left in consciousness. We can only hope to disentangle the more important elements from that complexity of elaboration which they have attained in experience; and then try to reconstruct into a consistent theory the elements thus gained by analysis. In pursuing this course it is most convenient and effective to follow, as far as possible, the order of nature. We thus find three stages of complexity and growth, as it were, which need explanation. These are: (1) The retinal image of the eye at rest and the sensation-complexes which enter into it; (2) the single eye as moved, and the influence of these movements; (3) the conditions furnished by the existence and relations of two eyes as active together.

Corresponding to the three sets of considerations just mentioned we may speak of three fields of vision, in the order of their relative complexity. These are: (1) The retinal field of vision, (2) the field of monocular vision, and (3) the field of binocular vision. By the first we mean that spatial arrangement of sensations of light and color, as points lying side by side, which is due to the excited expanse of the nervous elements constituting the retina, and acting without motion of the eye. The field of monocular vision includes all that can be seen by one eye, unaided and uninfluenced by the action of the other eye; while the field of binocular vision includes all that can be seen by both eyes.

Experimentally, we cannot construct, in the case of one who has had a developed experience of sight, any so-called "field of vision" which shall be irrespective of the existence and motion of both eyes. We may, however, apply our analysis to the supposed cases of a retinal field, and also of a purely monocular field, in order to *reconstruct theoretically the process by which the mind attains perception with two active and experienced eyes, constituting one organ of vision.*

The "Retinal Field" of Vision. — Let us close or blindfold both eyes, keep them as motionless as possible, and allowing time for all the after-images to die away, await the result. We shall soon perceive a mass, or "extensity," of light and color sensations, projected somewhat indefinitely in front of us. Some would describe this extensity of visual sensations as *felt* rather than seen. Within the entire expanse we can perhaps, strictly without the slightest motion of the eye, localize an indefinite number of minute points of color and light, lying side by side. This expanse of visual sensations has no fixed and well-defined outline, however; *nor can we localize any of its principal parts*, — upper right-hand, lower left-hand, upper centre, etc., — *without making minute excursions with both eyes*. If we turn the face upward, the "extensity" of visual sensations is now above us; if we turn the face downward, it sinks toward our feet. It has, indeed, a certain seeming of depth; its appearance is not that of a darkly colored wall or curtain placed close before the eye. But this seeming of depth is largely, if not wholly, due to the constant change in the color-tone and brightness of the minute portions of the field, which has an effect somewhat like that we get on looking at a very dense mist of particles differently colored and drifting.

It is perfectly plain that most of this perception of the locality of our visual extension is the result of acquired skill. Its position with reference to the entire body implies familiar and complex tactual and muscular sensation-complexes which have been accustomed to assure us of the position of the body and its members. When the field ascends or descends, for example, we can only make it seem so by producing in the neck the necessary "feelings of position." It would not be at all out of place to say that we then "see" this retinal field, above or below, with our necks.

Further experiment with the so-called "retinal field" serves to show us how complicated its character really is; and how much of accumulated experience and skill, won in the process of localizing a great variety of sensation-complexes, its perception involves. For example, a "phosphene" produced in either eye changes the character of the entire field. Or if one eye be opened, the "retinal field" of the closed eye is at once submerged in the objects, whose position, magnitude, and spatial relations belong to the "monocular field" of the open eye. Here again, however, this field of the open eye can be drowned in a shower of sparks caused by producing a strong phosphene in the field of the closed eye.

In general, it will be found that the extent of the retinal field, and the localization of the whole, as well as of its separate parts, are dependent upon the accommodation and motion of both eyes. The explanation of these facts would seem to necessitate the conclusion that *the perception of position and of localized areas, even in the two-dimensioned retinal field, depends upon the revival of associated and already localized tactual and muscular, as well as visual, sensation-complexes.*

Immediate Spatial Form of Visual Sensations. — On grounds like the foregoing, the advocates of the empiristic view (for example, Wundt) are led to the claim: "Our sensations of light do not immediately possess spatial form." On the other hand, various forms of the nativistic view insist that "we have native and fixed optical space-sensations" (so Professor James). In our judgment, science has as yet no perfectly certain means for deciding in favor of either of these claims. Experiment and observation certainly show that almost all of the *perceptive value*, and *associated perceptive influence*, which changes in sensations possess through activity of the eye, is acquired in the development of experience. We are warranted in affirming that the infant has no original visual intuition of the space-qualities and space-relations of anything, even including the members of its own body.

The ultimate question is, however, capable of statement in some such form as follows: When a number of the retinal elements are simultaneously irritated, without motion of the eyes, do the resulting sensation-complexes of light and color *originally* possess the quality of "extensity," —

whether in two or three dimensions? The problem proposed in this question is theoretical. No such irritation probably results in sensations of light and color without accompanying accommodation, and parallel or converging or diverging, movements of the organ. But would the resulting sensation-complexes possess this quality of extensity, in case they were not accompanied in the earliest development by tactual and muscular sensations? The question, we have already said, does not as yet admit of a perfectly unequivocal answer.

It should be said, however, in favor of the nativistic view, to some extent at least, that the mosaic structure of the retina suggests the eye's native perception of spatial form. The value of this structure for the development of visual perception can scarcely be understood at all, unless the irritation of each minute area of the nervous elements is represented by a local sign, or shading of the resulting sensation-complexes, in consciousness. Moreover, the spatial discrimination of which the eye is capable seems too great to be accounted for by changes in muscular sensation produced by accommodation and rotation on its axes. On the contrary, the limits of discrimination possible by perception with the eye correspond almost exactly with the limits of the retinal structure (see p. 255).

For the foregoing and other reasons we are inclined to hold that *spatial perception*, though at most in very inchoate and indefinite form, *is native to the mind as a synthesis of the qualitatively different sensations which result from stimulating simultaneously the retinal mosaic of nervous elements.*

THE CONSTRUCTION OF THE FIELD OF VISION.

The spatial form assumed by those sensations which are evoked by simultaneous stimulation of many retinal elements is, however, only one among several factors necessary in the construction of a "field of vision." *Vision*, indeed, in any sense of the word appropriate to the adult organ, involves a development of experience with moving eyes. The consideration of the simplest case requires that we should refer to the physiology of the eye. Only one small spot of the retina (the "fovea centralis") is capable of giving a clear image of an object. When we desire to see an object clearly we bring its image upon this spot and fixate it there. The point of the object which corresponds to the point of the image falling upon this spot is called the "point of regard" (sometimes "fixation-point"). In ordinary vision the complete perception of the object involves the rapid and constant change of this point of regard.

Rotation of the Eye-ball. — The wandering of the point of regard over an object may be considered as accomplished by rotating the eye upon a pivotal point, or centre of rotation, by motions that have different axes of rotation. This point is really a minute interaxial space, located about 1.24–1.77 mm. behind the middle of the optical axes. There are three axes to be distinguished, — an antero-posterior, a vertical, and a transverse. About these axes the six muscles (see p. 81) variously turn the eye, — one only being needed for movements inward and outward, two for movements upward and downward, and three for com-

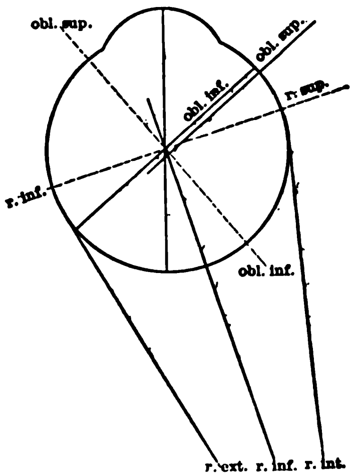


FIG. 79. — Diagram of the Attachments of the Muscles of the Eye, and of their Axes of Rotation — the latter being shown by dotted lines. The axis of rotation of the rectus, externus, and internus, being perpendicular to the plane of the paper, cannot be shown.

bined movements of inward or outward with upward or downward.

A line drawn from the centre of rotation to the point of regard is called the "line of regard." Such a line may exist, of course, for each eye. A plane passing through the two lines of regard is called the "plane of regard." When the head is erect and the line of regard directed toward the horizon, the eyes are said to be in the "primary position." Rotations of the eye, without torsion, may be regarded as movements of the eye upon its transverse and vertical axes. Rotation of the transverse axis displaces the line of regard either above or below; the angle which the displaced line thus makes with the primary line of regard is called "the angle of vertical displacement." The "angle of lateral displacement" is formed by rotation about the vertical axes.

Torsion of the Eye-ball. — By combining an apparent rotation on the antero-posterior axis with lateral or vertical displacements the eye is brought into a series of oblique positions. Such movement is called "torsion" of the eye. The angle which measures the amount of this movement is called "the angle of torsion." The law which is assumed to govern all of this class of movements — namely, combined movements sideways and either up or down — is called "Listing's law." It has been stated by Helmholtz as follows: "When the line of regard passes from its primary position into any other position, the torsion of the eye (as measured by the angle of torsion) in the second position is the same as if the eye were turned about a fixed axis standing perpendicular to both the first and the second positions of the line of regard."

Into the details involved in the application of the law that controls the rotation and torsion of the eye, we think it unnecessary to enter. One principle is of the highest importance; it is illustrated by all the movements of the eye. *The construction of the field of vision, whether monocular or binocular, is a synthetic mental achievement dependent upon the varying sensations which result from the wandering of the point of regard over the object.* Starting from its primary position, the eye may come round by a variety of circuits to the fixation of any particular point of the object. In the pursuit of these circuits it develops spatial series of muscular sensations and successively combines them with other series of sensations of light and color. Thus the form of the field of vision is dependent upon the wandering of the point of regard; and its construction involves a progressive synthesis of the mind.

Direct and Indirect Vision. — Let a sheet of white paper,

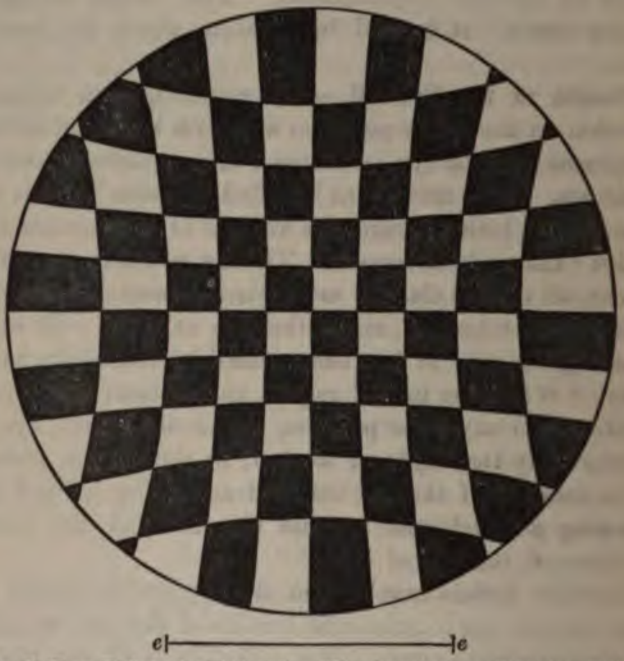
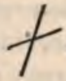
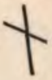
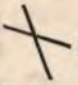
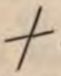


FIG. 80 (From Hering, after Hemholtz). — With the eye at the distance *e–e*, and fixated upon the centre, the hyperbolic lines which limit the black and white surfaces show the so-called "right lines" of the field of vision.

having a black dot in its centre to serve as a point of regard, be held at right angles to the line of vision with the eye fixed, in the primary position, upon the point of regard; then straight, thin slits of black paper upon this sheet will appear bent when lying outside of the vertical and horizontal meridians. Or let the after-images, left on these meridians by light falling through very narrow straight slits, be studied when torsion of the eye takes place, and these images will be found themselves to suffer torsion. The amount and the kind of torsion suffered by the after-images in the second of the above-mentioned experiments, may be discovered by use of a rectangular cross. The image of such a figure is itself distorted as follows for the different torsions of the eye: Upward and to the right, thus, ; upward and to the left, ; downward and to the right, ; downward and to the left, . By connecting the lines in the field of vision, as affected by all the possible torsions of the eyes, the accompanying figure is obtained (see Fig. 80).

It follows, then, that only those objects which are seen by *direct* vision (that is, whose images lie in the line of regard when the eye is in its primary position) appear in their actual place; objects seen in *indirect* vision appear at the place which they would assume if their retinal images were transposed to the point of regard and its immediately surrounding points. *The lines of the image do not correspond to the lines of the objective thing; they are constructed by a synthesis of sensation-complexes of local retinal signs and muscular sensations derived from the movement of the eye.*

Sensations from Accommodation of the Eye. — The muscular sensations — or, as they are sometimes called, the "feelings of effort" — which accompany changes of the focus of the eye in accommodating for near distances, enter into the data of visual perception. These sensations have not, however, a very clear and fixed value. If we regard a black thread, stretched vertically against a white background, with one eye, through an aperture in a shield, we shall find that we can tell little as to its absolute distance. Yet we can discriminate changes in its distance with considerable accuracy by changes in accommodation. Helmholtz found that he required a stronger accommodation to see a red than a blue stripe, through a tube.

Identical and Corresponding Points. — The theory of binocular vision, of normal developed vision with two eyes in motion and acting as one organ, introduces other important considerations. If the two retinas were exactly similar and perfectly symmetrical, they would admit of being theoretically superimposed. On such retinas, when the eyes were parallel, every single point of an object would have its image formed upon two "identical" points of both retinas, — upon points, that is, whose position would be mathematically the same with reference to the centre of each retina.

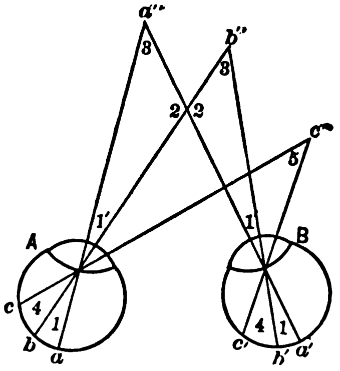


FIG. 81. — Diagram to illustrate the theory of corresponding retinal points. The images of objects at a'' or b'' or c'' will fall on corresponding points of the retina — a and a', b and b', c and c' — and be seen single.

No individual, however, has perfectly symmetrical or similar retinas; and the eyes of every individual are chiefly active in other positions than that called primary. Those points on the two retinas — ordinarily not precisely identical — which do in fact act together are therefore called "corresponding." In other words, the points of the two retinas, falling upon which the two images of a point in the object are ordinarily seen as one point, are corresponding.

In certain cases, moreover, points of the retina which do not customarily act together do, as a matter of fact, cover each other; in such cases the two points are sometimes called "covering" points. Indeed, experiment shows that considerable reciprocal substitution takes place among the different points of the two retinas. When the lines of regard lie parallel in the plane of the horizontal meridian of the two retinas, the vertical meridians do not correspond. Yet a vertical meridian of the left eye, with its upper end inclined to the left, may be conjoined with a vertical meridian of the right eye that has its upper end inclined at about the same angle to the right (see Fig. 80).

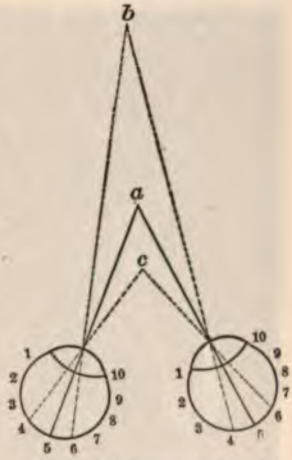


FIG. 82.—Diagram to illustrate phenomena of double vision. If the image of the point *b* fall in one eye on 6, and in the other on 7, the distance of the two images seen will equal that between 6 and 7. If the image of *a* fall on 5 and 5, it will be seen single, but if the image of *b* fall on the left eye at 6, and on the right eye at 4, it will appear double.

On this point also, then, the true theory of vision receives further confirmation. *Perception involves a fusion or synthesis of sensation-complexes, the nature and strength of which is determined, not simply by the mathematical construction of the eye, but by the data and development of conscious experience.*

The Double Images. — If we hold a finger before the eyes and look, not at it, but at a distant wall or at the sky; or if we point the finger at some distant object, and keep our eyes steadily fixed on that object; two transparent images of the finger, instead of one solid finger, will be seen. By experimenting in this way one solid object may readily be made to appear to pass through another. If two objects very similar — for example, the two corresponding fingers — be held a little way apart, at a foot distant and against a clear sky, one solid and two transparent objects may be made to appear, by combining the two middle images and keeping the two outside images dissociated. In the case of a regular small pattern — like the pattern of some carpets, or wall-papers, or the spaces of a wire-grating — the entire two systems of double images may be slipped the width of the pattern simultaneously to one side, and thus combined into a new system of solid forms.

Now it is obvious that the relations of the two images of an object cannot remain unchanged when the eyes are moved from their primary position. If the eyes, for example, are converged on any near object, only the images formed on the central spots of the two retinas are exactly identical and corresponding. These points alone are absolutely identical; but points lying very near to them are also seen single because they are, as it were, accustomed to act together. In other words, their local signs for both retinas are not so unlike that

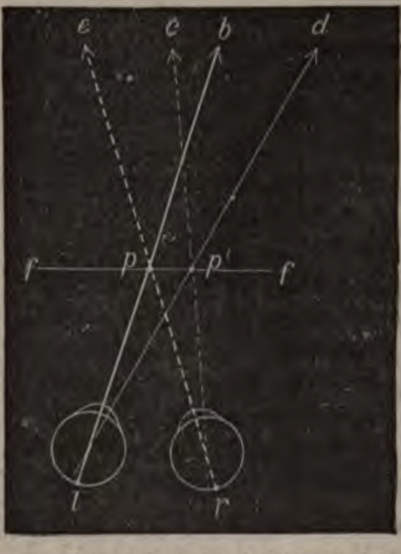


FIG. 83 (from Hering). — *f*, *f*, the sash of the window, and *p* the black spot fixated. On the left line of vision *l*, *b* lies a distant object, and on the right line *r*, *e* another object. The images of *b* and *e*, as well as the image of *p*, fall on the place of direct vision, and therefore on corresponding points of the two retinas.

they do not readily fuse. They have indeed been accustomed to fuse, with one another. All objects, however, which lie nearer or more remote than the point fixated by the eye are likely to be seen double; and those which lie much below or above, or to either side, of this point, are also likely to be seen double; that is to say, images of these objects do not fall on corresponding points of the two retinas.

Calculation of the Horopter. — The sum of all the points which are seen single, while the point of regard remains the same, is called the "horopter." Much ingenuity has been displayed in calculation, experiment, and discussion, to determine the exact nature of the horopter. It has been held to be a surface (plane or curved), a circle, a line, a number of connected points. It cannot be determined by calculation, because the eye in action is not a strictly mathematical instrument. It cannot be determined by experiment upon any one person, under one set of circumstances, for all persons under varying circumstances. *The horopter is a psychological affair, and its actual determination depends upon experience, habit, attention, and individual idiosyncrasies.*

With this understanding of the matter we give the following conclusions of Meissner as summaried and, in most respects, confirmed by Le Conte. With the eyes in the primary position, the horopter is a plane perpendicular to the median line of sight. [On the contrary, another observer, using a "very delicate method" of determining whether we are seeing double or not, decides that "the horopter is a circle where the fixation-point is median and nearly in the primary plane."] For all nearer points in the primary plane it is a line which dips toward the observer with an inclination to the visual plane, increasing with the nearness of this point of regard. When the plane of vision is turned upward, the inclination of the horopteric line increases; when it is turned downward, it decreases until it becomes zero at about 45°, and then expands into a plane.

Convergence of the Axes. — In fixating the point of regard for vision of a near object with both eyes, the lines of vision must converge upon the object. In convergence the eyes rotate upon the axis in opposite directions. In lowering the plane of vision, convergence naturally takes place; but in elevating this plane as in looking upon distant objects, the lines of regard diverge toward the parallel position.

Convergence may be "symmetrical" or "asymmetrical." In the former case, the two lines of regard are turned inward at equal angles, and the point of regard is kept in the median plane of vision; in the latter, the point of regard is outside of the median plane, and the two eyes are either turned at unequal angles inward, or else one is turned inward, and the other outward at a smaller angle.

Changes of accommodation naturally accompany changes in convergence of the eyes; and the resulting sets of sensation-complexes enter into the perceptive construction of space-form given to the object.

Influence of Effort in Vision. — A direction of attention and an effort to see are probably implied in convergence of the eyes. The eyes of new-born children, and eyes that are recently couched, as a rule, move in parallel lines. Arrest of attention brings the two eyes into use as one organ. In this way the sensations which arise when the muscles are innervated so as to produce convergence are of marked importance in the construction of the most elaborate and intelligent visual perceptions.

It is held by some authorities that the innervation of both eyes is equal even when the movements of the two are unequal; for each eye is then under the influence of two innervations, one of which is directed toward turning both eyes right or left, and the other toward turning them inward or outward. In one eye the two innervations would support, and in the other eye they would oppose each other. As a result they compensate each other; and the will may be regarded as guiding its pair of horses by a pull upon one rein. However this may be, there can be no doubt that the mental representatives of the different motions and positions are important factors in that mental construction, called the "field of sight."

Conditions of Stereoscopic Vision. — By the various "helps" already described stereoscopic vision is made possible. Without the joint activity of both eyes, it is probable that such vision cannot take place. If this be true, the field of monocular vision could be directly apprehended only as a plane; since all immediate perception of depth would depend upon the existence, and the coupling and uncoupling of the double images, together with the related changes in muscular and tactual sensations as the two eyes move upon their axes. It is certain that our immediate perception of the depth of objects with one eye, if such perception exist at all, is exceedingly inadequate.

It is undoubtedly true that, in adult vision, we do perceive objects to a certain extent stereoscopically with one eye closed. But it is probable that such perception is mediate and indirect; that is, it is accomplished solely by secondary means of vision. Among such means are the varying intensities of light and color, changes in apparent magnitude, etc., — all resting on the basis of associations long ago made by using the two eyes and the hands. By simple experiments with one's self one may be convinced how easy it is, when seeing with only one eye, to reduce all vision to indistinct patches of light and color on a visual plane.

There is no doubt that the double images which result from the use of the eye in motion afford data for the perception of the solidity of objects. It is more difficult to say just how this service is rendered. Artificial stereoscopic vision has made every one familiar with the fact that the two images of every object differ as furnished by the two eyes. The right eye sees the object farther around on its right side, the left on its left. Every minute portion of a solid object, provided such portion lies a little way out of the line of regard, instead of consisting of two exactly similar sets of lines that might be exactly superimposed, consists of two sets of minute curves that are partial images of its lines and are different for each eye. In some manner the perception of solidity is substantially aided by the fusion of these partial images.

Furthermore, in all ordinary stereoscopic vision the motion of the eyes successively unites and separates the double images of the objects seen. In viewing all objects of any size we may by attention become aware of the fact that we are sweeping over the field of vision with a moving point of regard. Even in the apparently instantaneous perception of a more minute object, the eyes are actually engaged in making short and rapid excursions around the primary point of regard. It has thus been found possible to claim, with much plausibility, that the localization of stereoscopic figures corresponds exactly with the kind and degree of motion necessary to produce fusion of the double images.

On the other hand, that movement of the eyes is not necessary to stereoscopic vision for trained adult eyes, is proved by what is known as "Dove's experiment." A field of vision, composed of two stereoscopic pictures, can be constructed when lighted by an electric spark; the $\frac{1}{24000}$ sec. which the flash of the spark occupies is far too brief a time to admit of convergence or of change in the point of regard. But we probably have in this experience one of those many cases where a complex product of perception results from the fact that the sensation-complexes primarily aroused by the stimulus call into consciousness, as fused with them, a variety of images of other secondary sensation-complexes. In other words, *instantaneous binocular vision of solidity and depth of objects, like monocular vision of solidity and depth in general, is secondary and dependent upon previous experience with both eyes in motion.*

Localizing of the Third Dimension. — Perception of the depth and distance of objects depends primarily, therefore, upon vision with two moving eyes. For such perception Hering has proposed the following law: All the lines or points whose images lie, with a given position of the point of regard, in the vertical horopter, appear clearly defined *on* a surface which is either plane or slightly cylindrical; and all the lines or points lying this side of the vertical horopter and whose images have a "crossed disparateness" (that is, the left one of the double images belongs to the right eye, and the right image to the left eye) appear *in front* of this surface; while those lying beyond the horopter and whose images have an "uncrossed disparateness" (that is, the right image belongs to the right eye, and the left image to the left eye) appear *behind* the surface on which whatever lies in the horopter is seen.

Of course, every law like the foregoing must be translated into terms of psychical representation in order to be a real *law of perception.* It implies the truth of the general theory, that interpretation of the images for the discernment of distance with motionless eyes is an acquired art, which is dependent upon previous combination of the retinal signs of both eyes with muscular sensations arising from the innervation and movement of the eyes.

The "old psychology" was accustomed to hold that we cannot perceive the third dimension — the depth and distance of objects — with the eyes. Such perception, it held, always results from muscular sensations of the entire body, or of the gross members of the body, which have become associated with visual sensations. In other words, a translation from sight into touch and muscular movement was thought to be necessary in order to see the depth and distance of objects. This view is undoubtedly erroneous. Depth and distance are immediately perceived by sight; but such perception comes, *primarily*, only through that developed vision which uses both eyes in motion,—changing the convergence of the axes and coupling and uncoupling the double images with a varying point of regard.

VISUAL JUDGMENT AND ERRORS OF VISUAL PERCEPTION.

Most of our experience in stereoscopic vision and vision of perspective of remote objects avails itself, as it were, of other helps that are not indispensable, absolutely, to the construction of a field of vision. These are sometimes called "*secondary*." Vision by their aid is often called "judgment," in distinction from so-called immediate perception. But judgment, in the sense of discerning and relating activity of mind, is involved in all perception. The only place where we can, apparently, fix any line of distinction lies between those data of sensation which are necessary to any normal binocular vision whatever, and those less primary means of assistance in seeing (or judging) the relative positions and distances of remoter objects that depend upon changing aspects of these objects. The need of so-called "secondary helps" is the greater because, at distances farther than from twenty to forty feet, the changes which accompany convergence and accommodation become practically inappreciable.

Five or more classes of secondary helps for stereoscopic vision, and vision of perspective for distant objects, may be enumerated. Among them the following are the more important.

Course of the Limiting Lines. — The lines which limit any object, when they are constructed by the moving eye, determine our perception of the distance and form, in depth, of that object. If these lines become confused, or run in directions strongly to contradict previous experience, we are liable to errors in perception. Especially when the bottom lines of a distant object are covered, its distance and shape in the third dimension become uncertain. The same arrangement of lines, when it admits of two interpretations, can be perceived in either one of two ways; for example, (as in the case of Fig. 84,) as either a staircase or a portion of an overhanging wall. Indeed, in viewing such an object a rhythmic change from one form of perception to the other may occur as a result of a rhythmic change in the fixation of attention and in accommodation (see also Fig. 85).

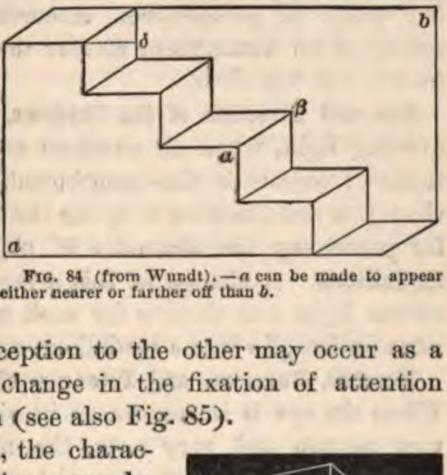


FIG. 84 (from Wundt). — *a* can be made to appear either nearer or farther off than *b*.

On the other hand, the character of the limiting lines may be such as to forbid more than one way of perceiving the object.

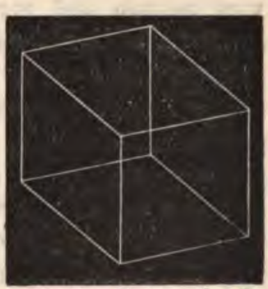


FIG. 85. — First one, then the other corner of the figure may be drawn forward, partly at will.

Mathematical Perspective. — The size of the angle of vision which is covered by the object, whether near or remote, is another of the so-called secondary helps. In this way objects of known size are seen as placed at a distance necessary to give them their apparent size. The street appears narrower and more distant, the houses lower and more remote, in the upper part of its visual picture. The tracks of a railroad appear to converge in the distance; and the same thing is true of the sides of the table or box near which we are standing.

Aërial Perspective. — More distant objects, on account of the amount of atmosphere through which the rays of light reflected from them have to pass, are more dim in outline and of a changed shade of color. These alterations in the character of the image furnish another secondary help in our vision of perspective. Accordingly, things are seen nearer in an atmosphere clearer than ordinary, more distant in one less clear.

Size and Direction of the Shadows. — In the morning or evening light, when all shadows are lengthened, the distance of objects is also lengthened. The arrangement of the lights and shadows is by far the most important datum for perceiving the character of objects like intaglios or medallions. A change in this arrangement, so as to substitute light and shadow for each other throughout, converts an intaglio into a medallion, and *vice versa.*

Number, Duration, and Intensity of the Spatial Series. — When the eye is in motion, as in vision of all objects not very minute and very near, the number, duration, and intensity of the different spatial series of sensation-complexes called forth by the motion are of influence in determining the outline-form, size, and distance of objects. The greater the *number* of the successive sensation-complexes it produces, the greater our estimate of the size of the object. For this reason the same extension of a line or surface, when broken up into parts by intersecting lines, seems larger than when perceived as an uninterrupted whole. This principle is made use of in repetitions of figures upon walls, columns, etc., in architecture.

The *intensity* of the sensation-complexes entering into a spatial series has also an influence on our estimate of the size of the object perceived. The size of the object is increased by viewing it with moving eyes when the muscles are lamed or tired. In paralysis of a muscle of the eye (for example, the *rectus externus*), objects seen by the eye moving in its shortened circuit are located where they would have been if the same intensity of muscular sensation had been necessary to bring them to this position with a normal action of the muscle. On this principle the size of parti-colored and mottled objects is increased. But the absence of a standard of judgment may have the same effect on the repetition of the standard; thus both unusual monotony and great variety may have the same effect in magnifying the size of the perceived object.

The *duration* of time of the eye's activity in perception also has a marked influence on our estimate of the size of the object. The length of time occupied in mastering complex objects may be interpreted — especially if the attention required is somewhat strict and painful — as extensive magnitude.

Influence of Memory and Will upon Visual Perception. — In all adult vision the mind takes its token, as it were, from a very incomplete outline sketch of the object and "makes up," of itself, the complete object, by drawing upon its store of *memory-images*. Visual perception is, therefore, not simply according to the objective character of so-called "things" to be seen; it is also very largely according to the mind's custom in perception. Accordingly, when the mind's habit is broken up for a time, its interpretation of the sensation-complexes, and its synthesis of them into recognized objects of sense, may be much altered. For example, the effect of the "pseudoscope," — an optical instrument which by exchanging the two stereoscopic pictures converts convex into concave, and *vice versa*, — when applied to a complex object, like a landscape, is very bewildering. The same thing is also true of the "telestereoscope," — an optical instrument which enables us to see a larger portion of a distant object than is possible with two ordinary eyes, somewhat after the fashion of a pair of optical organs in the sides of a gigantic head.

Within certain limits we can see what *we choose* to see. It is held by many excellent observers that, without any change of focus or of convergence, we can render any object in the field of vision clearer by directing attention upon it. Even when the object lies far to one side of the field, this effect — though difficult to produce — may be attained by trained observers. In the case of perception with a moving eye we can, to a certain extent, decide the area over which the point of regard shall sweep and the relative attention to be given to the subdivisions of this area. Furthermore, and especially in the case of geometrical figures, it often lies in our power to decide how we will interpret certain data which admit of more than one interpretation.

Accuracy of Visual Perceptions. — Our estimate of the length of visual lines and of the size of visual surfaces is relative, not absolute; it falls, therefore, to some extent, under the principles discussed in Weber's law. The fineness of ocular judgment is greater for horizontal than for vertical distances. It is much less accurate when the distances compared lie in different directions. In particular, points lying at a vertical distance of 20 mm. are estimated as equally far away with those lying at a horizontal distance of 25 mm. Estimates of direction and distance are much more inaccurate when made with only one eye.

The principal data which enter into visual judgments of length, etc., are probably the local signs of the retina as associated with memory-images of sensations of motion, and minute changes of the coloring of muscular sensations as directly dependent upon movement in accommodation and convergence. Helmholtz found that a displacement of the middle one of three nails, when set in an otherwise straight line, corresponding to a variation of only 0.0044 mm. in the position of the retinal image, could be detected. And Weber showed that a distinct muscular sensation is attached to a displacement of the most sensitive spot of the retina of not more than $\frac{1}{521}$ of a Parisian line.

More Complex Estimates of Visual Magnitudes. — The real and the apparent magnitude of an object are, of course, so related that one is dependent upon the other. By the "apparent magnitude" of an object we mean its size as perceived (or judged) by the magnitude of the angle covered by its image, or by the extent of the external surface simultaneously excited by the rays of light reflected from the object. The "real magnitude" is its size as definitely measured by certain fixed standards of measurement formed on the basis of generalizations from the use of both eye and hand.

Distance, apparent magnitude, and real magnitude may therefore be connected as three factors of one problem proposed to the perceptive power of the eye. Given both the apparent and the real magnitude of an object, and we judge of its distance according to our experience of how large an object of the known size ought to look at an assumed distance. The distance at which the object is perceived may be said to be an hypothesis framed to reconcile the known with the apparent magnitude. Distance and apparent magnitude being given, real magnitude is judged as that which the object would need to have in order to appear so large as it does appear at the known distance. When either of the two necessary data is lacking or obscured we fall back, as it were, upon such secondary helps as aërial perspective, etc.

Perception of Motion by the Eye. — The data and processes already described furnish the explanation of our perceptions of the direction, speed, and extent of the motion of objects, by the eye. Here, as elsewhere, we seem to require a distinction between such perceptions as are most primary, and involve the fusion of the local signs into those spatial series which make it impossible for consciousness to disentangle the component factors, and those secondary perceptions where judgment is consciously exercised in estimating the value of various more or less separable data. The latter form of perception is more correctly described as an "inference" to the motion of a body from seeing it at different places in space at successive intervals; the former appears rather as elementary and immediate perception of motion on the basis of just perceptible changes in the requisite sensation-complexes. We may have a perception of motion when the interval between the two appearances of the moving body is too minute to be observed. For example, two impressions 0.045 sec. apart can barely be distinguished as two; but the direction of the motion of a light can be perceived when the difference between the beginning and the end of the motion is only 0.014 sec. On the lateral portions of the retina two disks, so near as not to be seen as two, can easily be seen to change place on the slightest movement.

In general, our judgments in perception of motion by the eye imply the existence of some point which may be regarded as fixed, and the application of a standard of measurement. If no one object in the field of vision is recognized as stationary, such perception becomes exceedingly vague, and the perceptible mininum of motion becomes about ten times as great. When the organ is in the primary position, the point of regard furnishes the means for placing things in right relations to ourselves and to each other.

Perception of motion may then arise in one of two way
The object may change its relative position in the field

vision; this involves the successive stimulation of contiguous areas of the retina with images that are sufficiently alike to be regarded as one real object. But perception of motion may also be produced by the successive stimulation of the same area of the retina with images that are too dissimilar to be regarded as one object.

In perceiving all movements of much extent, however, the eyes follow the object. When both eyes move in such a way that the point of regard remains fixed on the object, our perceptions of the direction and amount of motion are dependent upon changes in the muscular and tactual sensations evoked by the eye's changes of position. That is to say, we judge the movement of the object on a basis of judgment as to the positions and movement of the eyes themselves. But we may need to turn the head, or even the body, in order to follow with the eye the moving object. In this case the sensation-complexes originating in the action of the muscles and skin of the head and neck, etc., furnish indispensable data which enter into our computation. These data must have such an established value in consciousness as to indicate the successive positions of the moving parts of the body, or else we cannot "see" (perceive or judge) how far, and in what direction, the object has moved.

Perception of objects in motion implies perception of objects at rest. Objects are perceived at rest, either when, our organs of vision being themselves at rest, the images of the objects do not change their position in the field of vision, or when the sensations of motion occasioned by moving the organs are such as we know by experience correspond to those changes in the position of the images which are occasioned by objects actually remaining at rest.

Thus what is really moving, and what is really at rest, in a complex field of vision, often becomes a very complicated and difficult problem for the mind to solve on data furnished by the eye alone. Few things connected with the general subject are more impressive than the errors of visual perception which originate under unfavorable circumstances. Indeed, where we do habitually solve the problem successfully, the data on which we solve it are apt to be overlooked. They are always very difficult of disentanglement. Few people have noticed that, in every case of the hundreds daily occurring, when we change the point of regard from a very remote to a very near object, the two fields of view belonging to the two eyes rotate in opposite directions, while the middle visual line maintains its position in the median plane.

After-images of Motion. — Those sensation-complexes which the mind builds into perceptions of motion, like other sense-impressions, leave an *after-image*. In this way very confusing results are frequently obtained. For example, if a rotating disk, with a spiral drawn upon it, be suddenly stopped rotating, the points previously seen to move toward the centre are now seen to move in the opposite direction. If one eye view a rotating disk directly, and the other through a reversion prism, the two impressions result in confused perception; but if the disk be looked at with one eye until fatigue occurs, and then that eye closed, and a white surface looked at with the other eye, an after-image of the disk rotating in the opposite direction will appear.

General View of So-called "Errors of Sense." — The right to use the term "errors of *sense*," has sometimes been disputed, on the ground that sense cannot err, and that all error is really of the judgment. But this attempt at distinction is based upon a complete misunderstanding of the nature of perception. All *perception* involves discrimination and judgment; but errors in this sphere are not by any means confined to the making of distinctions which can be corrected at will by revision of the data, as it were.

When one sees a square of white paper green because it is on a red ground, or yellow because it is on a blue ground, it is certainly correct to say that the senses are in error. The remark of Lotze is not unjustifiable when he affirms: "The whole of our apprehension of the world by the senses is one great and prolonged deception."

We should prefer, however, to call attention to such facts as the following: *Clear vision is always mental interpretation.* Objects of sense are in no case exact copies of ready-made things. *The data*, or *motifs*, and *the laws* of the mind's constructive and synthetic activity, *are precisely the same when errors of sense are committed as when so-called true and exact perception takes place.* Errors of sense differ from hallucinations, because the former result from the activity of an organism which is normal in structure and function, while the latter do not.

The errors of visual perception are almost innumerable; they can be only partially classified, according as they fall under some one of the foregoing principles rather than others. Certain of the more important classes are the following: —

Errors Due to the Relations of the Double Images. — We have already seen that near objects erroneously appear double when the eye is adjusted for distant objects, and distant objects appear double when the eye is adjusted for near distances. Solid objects are sometimes seen through other solid objects; one object sometimes appears two, and two objects appear one; — and all according to the law of the correspondence or non-correspondence of the two retinal images.

A very old psychological puzzle is proposed in the question, Why is vision single, when performed with two eyes? The question implies a complete misunderstanding of the whole theory of visual perception. We do not see the images at all; but — as we have learned from the facts of stereoscopic vision — a chief condition of the single vision of all solid objects is that they *shall be* seen with two eyes. The fusion of the data belonging to the formation of the two images is the psychical condition of the perception of one solid object.

Errors of Mathematical Perspective. — A large class of visual errors fall under laws which regulate the smallest observable differences in the muscular sensations as related to the clear perception of the lines, angles, and surfaces of the object perceived. The fact that vertical distances are regularly perceived as larger than equally large horizontal differences has already been mentioned. On trying to draw a cross with limbs of equal length one is apt to get the vertical dimensions too small; exact squares appear higher than their breadth. When comparing magnitudes in the upper part of the field of vision with those in its lower part, one is likely to overestimate the former. The upper and lower half of an "S" or a figure "8" appear of nearly the same size; but when they are inverted ("S" and "8"), the difference in the size of the two halves is exaggerated.

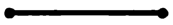


FIG. 86.

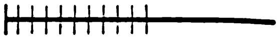


FIG. 87.

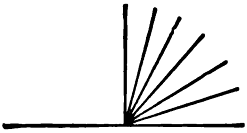


FIG. 88.

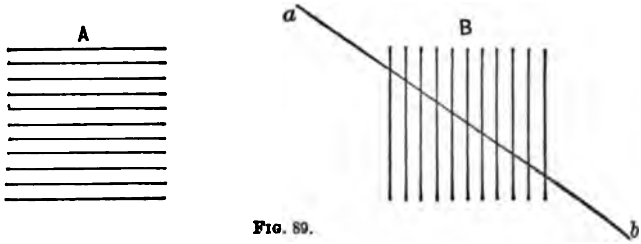


FIG. 89.

Errors arising from the Number and Variety of Impressions. — We are frequently deceived in a remarkable way by the manner in which the field of vision is filled up. Such errors fall in part under the principles of mathematical perspective, but also in part under the principle which converts into "extensity" the number and intensity of our sense-impressions.

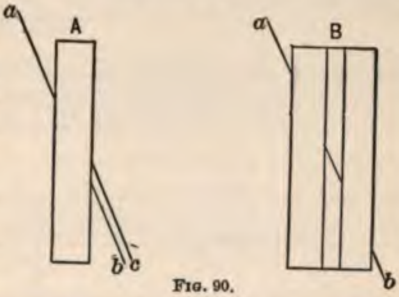


Fig. 90.

If the horizontal distance between two points be exactly half filled with a line, this line will appear to some observers longer than the remaining empty space. A square intersected by parallel horizontal lines appears elongated upward, but one intersected by parallel vertical lines appears elongated sideways. If one of two

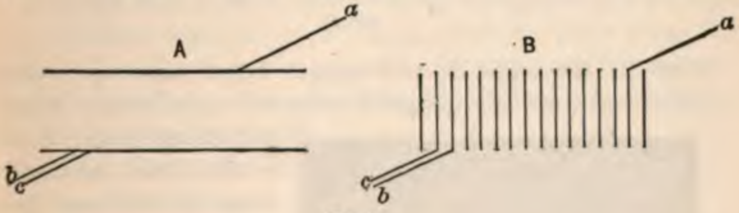


Fig. 91.

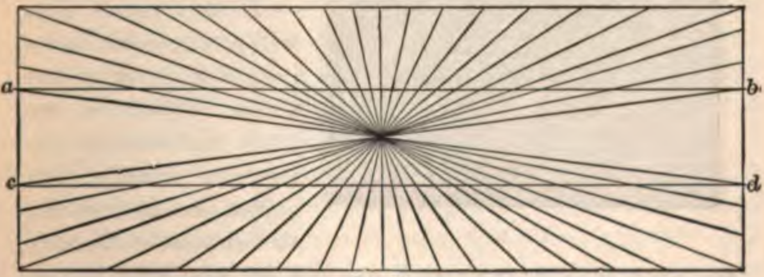


Fig. 92.

right angles, formed by a line drawn perpendicular to a horizontal line, be filled with several lines diverging from the point of the angle, it will appear larger than the other right angle, and the perpendicular will seem bent. Many surprising visual errors result from combinations of this and the foregoing principles.

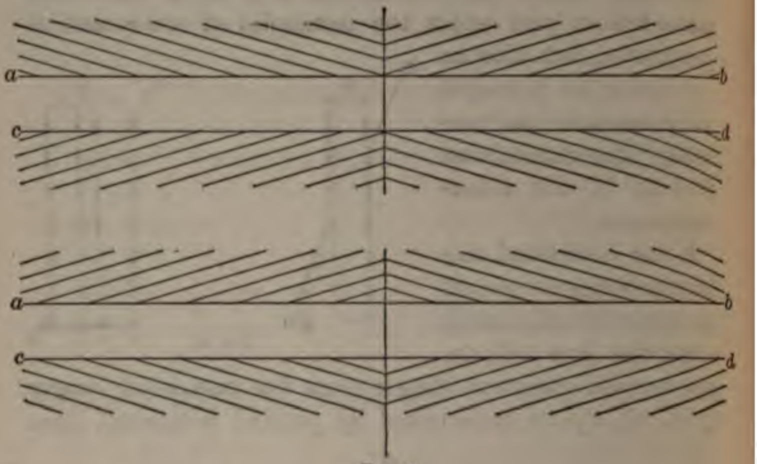


FIG. 93.

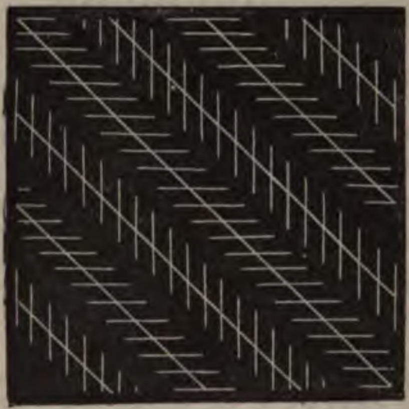


FIG. 94.

Errors of Imagination under the Law of Habit. — If the visual data will at all permit it, we incline to perceive any visible object as we know that similar objects are usually perceived. In other words, *the synthesis of the various sensation-complexes with one another, and with the re-*

vived and associated memory-images, falls under the law of habit. This principle is constantly taken into account by the pleasant illusions of art. Their success in — as we say — "deceiving" us is not strange; for this success rests upon the same basis as all the normal and habitual perceptive activity of the mind.

Many errors in our perception of motion by the eye are to be explained on the foregoing principle. It makes no difference with the result whether the data for such perceptions are furnished by actual changes in the position of external things, or by changes confined within the organs of sense. We incline, for example, where two objects are seen to be changing their relative position, to perceive the smaller of them as in motion; we also overestimate the speed of small bodies in motion, and underestimate that of large bodies.

Errors chiefly Due to Inter-cerebral Changes. — The attempt to discover a physiological explanation for such errors as belong to the class last-mentioned brings us, of course, to the cerebral visual areas as their primary source. We have already seen that the phenomena of the contrast of colors (p. 264 f.) must depend upon certain inexplicable activities of the central organs. The same thing is true of those errors of sense which occur in connection with the strife and prevalence of contours, and with the binocular mixing and contrast of colors.

If a well-defined image of some colored contour be formed on one retina, and on the corresponding area of the other the image of a uniformly colored background, only the former will be visible. This is called the "prevalence of contours." But if the contours of the two images of differently colored objects cross on the retinas, then sometimes one and sometimes the other of the two colors will be perceived at the place of crossing. This is called "the strife of contours." If four squares of paper, — otherwise exactly similar, — two of red paper and two of blue, have their images combined, the middle one of the binocular images will be sometimes redder, and sometimes bluer, than either of the side-images; but in no case will it exactly resemble either of them. This is called the "binocular mixing of colors." If a white stripe be placed upon a black surface and divided into two images, the right one of which is formed by looking at one half through blue glass, and the left by looking through gray glass, then the right image will be seen blue, but the left will be seen yellow. This is called "binocular contrast of colors."

Now in all these and similar cases of deception it is plain that the physiological conditions of the mixing and contrast of the contours or colors depend upon combined and contrasted changes of the brain rather than of the external organs of sense. None the less, but even the more obviously, however, does their psychological explanation fall under the laws of that theory of visual perception which we are illustrating.

The peculiar perception of luminosity which a slightly ruffled sheet of water has, is due to such a struggle between the two fields of vision of the two eyes as results in a rapid alternation of the white and gray images. It may be produced by combining two stereoscopic pictures of like contour, but one of which is black with white lines and the other white with black lines.

Certain optical illusions of motion, moreover, involve very obscure and complicated applications of these and other physiological principles to the centres of the brain. For example, in watching a fall of water for a long time, the steady succession of images passing over the retina sometimes ceases to be perceived as a motion at all. The images of a stationary body on the same retinal region may appear to be moving in the opposite direction. In certain cases, even the same elements of the retina, when stimulated simultaneously, may give rise to impressions both of motion and of rest. For errors of visual perception like these, unknown laws of cerebral action need to be assumed. The data, in the form of sensation-complexes, and revived and associated memory-images, are so complicated and thoroughly fused that they scarcely admit as yet of a satisfactory psychological analysis.

THE DEVELOPMENT OF VISUAL PERCEPTION.

We have now seen what are the "sense-data" which the mind has, as it were, at its disposal for the construction of spatial perceptions by sight; and, also, what are the more important psycho-physical laws followed in the process of construction. Visual space implies coherent complexes of light- and color-sensations systematically arranged. The arrangement involves native activities of the mind in dependence upon the action of the bodily mechanism of sense. But it also implies mental growth, development under the influence of experience. Perhaps we may rather say that the development of visual perception *is* the organization of certain sensation-complexes, arising on occasion of the activity of the organ of vision, into a visual experience.

It is, indeed, difficult if not impossible to tell just where the limits must be drawn between what is native and what is learned. There can be no doubt, however, that seeing colors (or having observed localized or wholly unlocalized sensation-complexes of light and color) is a far more simple and primary activity than seeing colored surfaces. The perception of such surfaces — of a system of light- and color-sensations related to each other as side by side in space-form — results in experience from the fusion or weaving together of several spatial series of sensation-complexes. It involves muscular and tactual sensation-complexes caused by the motions of the eye for parallel turning, for accommodation, and for convergence.

But the visual perception of extended objects, as adult experience possesses it, requires binocular vision with moving eyes. The firm spatial connection of all the parts of the field of vision requires that a system of lines of direction should be fixed. These prescribe the objective points at which the sensations produced by exciting together the different pairs of the covering points of the two retinas must appear in visual space. To establish such spatial connection, both eyes must move in their joint action as a single organ of vision. Thus the field of binocular vision is built up by an order of experience which consists in the successive mastery of more and more complex problems.

The visual perception of depth involves a later and more complex training as the result of experience than the perception of two-dimensioned extension. To solve the problem of depth, binocular vision with moving eyes — thus calling forth the muscular sensations that accompany convergence, and the resulting combination and separation of the double images — is necessary. Here, too, the presence and assistance of the so-called "secondary helps" are extremely important. Thus a knowledge of the solidity and distance of objects is developed. But this more complex experience, when once obtained, modifies completely what is really more simple and elementary. What we see of solid and distant objects with one motionless eye, depends upon what we have learned to see with both eyes in varied motion and reliance also upon all the available secondary helps. The apparent "immediateness," or natural and "intuitive" character, of the construction of the field of sight in monocular vision is one of the many illusions with which the evolution of all our experiences is interpenetrated.

These general remarks apply to the following special topics connected with the development of visual perception.

Vision of Things Upright and in Correct Spatial Relations. —Among the psychological puzzles often propounded as though they were of especial difficulty we may notice the following: Why do we see the upper part of the object by means of the lower part of the retinal image, and *vice versa?* and, Why do we see the right side of the object by means of the left side of the retinal image, and *vice versa?* In other words, why do we see the external thing with its parts up and down, and right and left, exactly the reverse of the parts of the image? To such questions the right theory of visual perception and its development offers a ready reply. Strictly speaking, we do not see either the retinal image or the *extra*-mental material thing. The field of vision is a subjective affair, and is like neither of these two. Perception is indeed dependent upon the formation of the retinal image as one occurrence in a chain of physical changes; and the formation of the image is, in the same way, dependent upon the action of the rays of light reflected from the object: but the object seen is not a copy of either image or extra-mental thing.

The field of vision gains a locality in objective space only as we develop our knowledge of the relations which our entire body and its different parts sustain to the earth and to the different things surrounding us. The use of such terms of position as "up" and "down," or "right" and "left," implies such knowledge. The massive feelings arising from the condition of the skin, muscles, joints, and fluids of the body, keep us informed of our general relations to the earth and to objects on its surface. The head is the upper part of the body, or part farthest away from the ground; the feet are the lower parts, in contact with the ground. When the eyes move downward, the lower parts of the body and objects situated on the ground come successively into the field of vision; but when the eyes are moved upward, these parts successively disappear from the field of vision. "Right" is the direction in which the eyes, on moving, find the right hand and objects on its side; and "left" is the direction in which the eyes look for the left hand and for objects contiguous to it.

Joint Action of Eye and Hand. — These two organs of the body, from the very beginning to the end of life, are constantly assisting each other in the work of perception. An almost continuous process of translation is taking place between the two. What is true in such a high degree of the eye and the hand is true in less degree of the eye and all the members of the body of whose spatial dimensions and relations visual images can be correctly formed. So also in our perception of external things the eye, on the one hand, and the tactual and muscular organs, on the other hand, aid each other in the work of localizing.

Experiments have been undertaken to show the *degree of accuracy* which can be attained in translating perceptions between the eye and the skin and muscles. Donders made use, for this purpose, of a very small induction-spark which was to be touched with the index-finger. In fifty experiments, made for distances of 60 to 610 mm., along the same line of regard, in perfectly dark surroundings, the distance was estimated right four times, overestimated 34 times, underestimated 12. The greatest errors were + 35 and − 34 mm. When the surroundings were visible, the spark seen with open eyes, and then estimated by the finger with closed eyes, the errors were reduced. Localizing in this way, with the object out of the line of regard, was much more inaccurate.

Experiments have also been made to test the relative accuracy with which the three perceptive organs — eye, hand, and arm — will receive perceptions of distance from each other and translate them into their own terms of expression. Jastrow thus concluded that, when the eye is both the receiving and the expressing sense, lengths less than about 38 mm. are underestimated, and lengths greater are exaggerated. But when the hand is both the receiving and expressing organ, lengths less than about 50 mm. are exaggerated, and lengths greater underestimated. The arm, in expressing all lengths received from the eye, exaggerates them; but it underestimates all lengths received from the hand.

Let us suppose a person to stand blindfold before a vertical table and make with one hand an excursion of definite length along a thread, — moving at the same time, by will, and unguided by any thread, the other hand to the amount supposed to represent the same length. If the unguided hand starts from a point higher up than the other and moves upward, it moves less than it should do; if it moves downward, it moves more than it should do.

All such results as the foregoing show plainly that the interpretation, back and forth, of visual and muscular distance is a matter of very complex development, and is at best only imperfectly attained. It is not possible to announce any one principle which will explain all the errors so persistently committed in this kind of interpretation. We believe, however, the following two principles are chiefly influential.

In the first place, each sense, when expressing its estimate of perceptions received from itself or from another sense, tends to approximate the dimensions which it is accustomed to judge most accurately. In the second place, in all such work of translation, memory-images of visual perception are the guiding and dominating factors. For example, even when moving about in the dark, in a familiar room, we carry a memory sight-picture of the position of the objects in the room, as well as of the size and shape of the room, to guide our muscular and tactual activity. When we try by arm and hand to indicate the position of any member of our own bodies, or of any external object, we are accustomed to make our estimate first in terms of memory-images of sight, and then translate through the medium of these images into the required "expressing" sense.

In closing this subject, attention should be directed to the limitations of explanation with which the science of physiological psychology everywhere finds itself encompassed. One of these limitations is, of course, reached so often as we are obliged, in offering our explanations, to recur to the "natural" or "native" or "intuitive" operation of the mind. Nor will the penetrating student of perceptive processes imagine that any historical or experimental description which can be given of such processes will explain the origin of so-called "space" as a mental form of activity. The study of the processes emphasizes the conclusion that *the space-form of all perception is mental;* it is not a copy, or representative, of ready-made *extra*-mental existences called "things." And we only anticipate a conclusion warranted by our entire science when we repeat: The field of vision is a subjective affair, and so is the field of touch. The same psychical subject which reacts upon the stimulation of the nervous elements, in the form of various quantitatively and qualitatively different sensation-complexes, constructs by its synthesizing activity, in the development of its own life, all the so-called "objects of sense."

CHAPTER XV.

TIME-RELATIONS OF MENTAL PHENOMENA.

SINCE the work of Donders in 1868, no single subject in the general study of mind — with the possible exception of Weber's law — has made such a large collection of statistical data as that known by the title "psychometry." The aim of this branch of experimental psychology is to determine exactly the *time-relations of mental phenomena.* If the results are to be estimated by the number and novelty of the principles established beyond doubt, they must be admitted to be remarkably small. Countless trials, and innumerable tables of statistics, from which already familiar generalizations (if any generalizations whatever) are somewhat ostentatiously derived, thus far comprise the chief treasures of the science of psychometry. The amount and hopefulness of the work accomplished, as well as some promise of intrinsically important results, require, however, that the subject should receive a brief treatment.

Method of Experiment. — The general problem in all classes of trials under this head is essentially the same. It is the accurate measurement of the interval which elapses between peripheral stimulation of a certain organ of sense and some form of resulting motion, such as signifies that more or less complicated physiological and psychical processes have intervened. The electrical current is ordinarily used to mark the precise instants when this interval begins and when it terminates. The stimulus may consist in the flash or crackle of an electric spark, in the sounding of a bell or a falling ball or a musical note, in the appearance of one or more colors or figures, or letters or words, etc.; and the resulting motion may be with the finger pressing a key, with the foot or hand closing or breaking a circuit, with the vocal organs calling into a tube, etc. All such experiments may be repeated upon many persons, an indefinite number of times, and under every conceivable variety of conditions and circumstances.

The difficult and valuable part of all experiments in psychometry is the analysis of the complex cerebral and psychical factors implied in the processes. The difficulty of this analysis is due to the speed, complexity, and subtle variability of the processes which are to be analyzed. The value of the analysis — if it can be satisfactorily accomplished — depends upon the hope of discovering what are the nature and the relations in time of our mental processes, and what the nature of their dependence upon processes in the nervous system.

Simple Reaction-time. — The point of starting in all experiment to determine the time-relations of mental phenomena is the fixing of "simple reaction-time." The entire interval between the instant when the stimulation of the organ of sense takes place and the instant of the resulting movement of some member of the body is called "reaction-time" (sometimes "physiological time"). Reaction-time is *simple* when everything which tends to complicate the processes, and so to lengthen the interval between stimulation and motion, has been eliminated. Simple reaction-time is obtained in response to a single sensation of known quality, the instant of whose appearance is expected, by executing a single natural and accustomed movement.

But the simplest reaction-time is, in fact, a very complex affair. It involves, of necessity, not less than seven elements: (1) An action of the stimulus on the end-organ of sense; (2) centripetal conduction in the nerve; (3) the same in the spinal cord and lower parts of the brain; (4) transformation of the sensory into the motor cerebral process; (5) centrifugal conduction in the lower brain and cord; (6) the same in the motor nerve; (7) setting-free of the muscular motion.

Psycho-physical Time. — Of the seven foregoing processes involved in reaction-time the one numbered (4) is much the most interesting to physiological psychology. It is called "psycho-physical time" and, in its more elaborate form, has been analyzed by Wundt into three psycho-physical factors: these are, as described after an analogy derived from the sense of sight, (1) entrance into the *field* of consciousness, issuing in "perception"; (2) entrance into the *point of clear vision* in consciousness, issuing in "apperception" (*i.e.* clear and attentive perception); and (3) the excitation of the "will," which sets free in the central organ the registrating movement. For each of these factors time is required. Each of them is psycho-physical, — that is, each comprises physiological processes in the central organs and simultaneous corresponding changes in consciousness. Given, as the result of a sufficient amount of experimenting, the average simple reaction-time, the problem becomes: to find the three factors of psycho-physical time (namely, "perception-time," "apperception-time" or discernment-time, and "will-time"), for all possible conditions and degrees of complexity and delay of the psycho-physical processes.

Effect of Inertia. — Since the nervous system is composed of related material elements, we should expect that some time would be absorbed in realizing the effect of stimulation as an activity of the different organs. We should also expect that, when once excited, the effects of the excitement would continue for some time after the stimulation has ceased. It is difficult, however, to demonstrate the truth of our expectations in the case of the motor nerve. The nerve does not seem to require that period of latent excitation (about $\frac{1}{100}$ sec.) which the muscle requires for action under the influence of electricity. The case of the end-organs is, however, more clearly defined by experiment. These organs are capable of receiving only about so many separate excitations in a given unit of time. The number of such separate excitations is different, however, for different senses; it depends also upon the quantity and quality of the stimulus used, upon the place of its application, etc. More than a certain number of applications of the stimulus to an end-organ of sense results in fusion of the otherwise successive sensations.

Smallest Interval for Sensation of Touch. — The results of experiment to discover the greatest promptness with which the organ of touch will act — or, in other words, the smallest interval possible between two separable sensations produced by repeated stimulation of the skin — differ very greatly. One experimenter has placed the limit at 27.6–36.8 nervous shocks per second; another at 480–640; another at about 1000.

Smallest Interval for Sensations of Sound. — The noise of the electric spark, heard with one ear only, has been distinguished at intervals of only 0.00205 sec. By using the click of a revolving toothed wheel the interval was thought to be fixed at 0.016 sec. It is increased to about 0.064 when the sounds are heard with both ears. Of course, far fewer musical sounds can be heard in the same amount of time, since a considerable part of a second must be consumed before the tone is established, as it were. The number of separate sensations of sound possible under the most favorable circumstances may, then, be placed at about 500 per second.

Smallest Interval for Sensations of Sight. — In ordinary daylight, rotating disks, whose surface is part white and part black, become gray (that is, the sensations fuse) when they attain a motion of about twenty-four per second. With care, under favorable circumstances, the stimuli of light sensations may be kept separate at only about $\frac{1}{40}$ sec. If one stimulus strikes the *fovea centralis* and the other a point of the retina 6 mm. off, the smallest interval for distinct perception becomes about 0.076 sec.

If the inertia of the eye for different color-sensations were very different, objects would be seen of varying color according to the time during which the rays from them acted on the retina. But the smallest interval for the perception of different colors is only very slightly different. Recent experiments to determine the length of time, expressed in 0.001 sec., which is required to distinguish each color exposed from a correspondingly bright shade of gray, yielded the following mean-values: Red, 1.28; orange, 0.82; green, 1.42; blue, 1.21; violet, 2.32. From these results the principle was generalized that "the time colored light must work on the retina, in order that it may be seen, increases in arithmetical progression as the intensity of the light diminishes in geometrical proportion." *This time probably represents inertia of the brain and nerve-tracts as well as of the retina.*

For the other senses — smell and taste — the measurement of the smallest interval is too inaccurate to admit of satisfactory discussion.

Smallest Interval from One Sense to Another. — The time required for discrimination of successive sensations, when they belong to different senses, is even more variable. It depends, of course, upon the two senses between which the discrimination is made, upon the intensity of the sensations compared, upon which of the two sensations follows the other, etc. For example, the average interval between sight and touch (sight following) is given at 0.05 sec.; between sight and hearing (sight following) at 0.06 sec.; between sight and touch (sight preceding) at

0.071 sec.; between sight and hearing (sight preceding) at 0.16.

Mean-values of Reaction-time. — As has been already seen, the point of starting in all experiments in psychometry is the determination of simple reaction-time. But the value of this factor varies, by smaller or larger degrees, with different individuals, and with the same individual under different circumstances. By repeated experiments, under the most favorable conditions, the time absorbed by the sensory-motor cerebral processes is reduced as nearly as possible to zero. The mind is then said to act as nearly as possible in a purely mechanical way under the influence of training and habit. Even then the simple reaction-time of different individuals is markedly different. For example, from "hand to hand" (that is, one hand being hit by an electrical current and the other acting to press a key) the reaction-time as given by different experimenters varies from about 0.1087 sec. to about 0.1911 sec. The reaction-time from eye to hand varies from about 0.150 to 0.225 sec.; from ear to hand, 0.120–0.182; from neck to hand, 0.154, etc.

According to certain authorities the reaction-time for the sensation of cold is somewhat less than for heat: for example, for *cold*, near edge of eyelid, 0.135 sec.; upper arm, 0.150; abdomen, 0.226; inner surface of thigh, 0.255; and for *heat*, 0.190, 0.270, 0.620, and 0.790 respectively. Experiment amply confirms the familiar experience that the contact of objects is much quicker perceived than their temperature.

We may conclude, then, that *under the most favorable possible conditions the reaction-time can scarcely be reduced to $\frac{1}{10}$ sec., while it rarely rises much above $\frac{2}{10}$ sec.*

Increased Intensity shortens Reaction-time. — The effect upon the reaction-time, of increasing the stimulus, for sensations of sound has been studied by Wundt with the following result: —

Height of hammer falling.	Reaction-time. Sec.	Height of ball falling.	Reaction-time. Sec.
1 millimeter.	0.217	2 centimeters	0.161
4 millimeters	0.146	5 centimeters	0.176
8 millimeters	0.132	25 centimeters	0.159
16 millimeters	0.135	55 centimeters	0.094

Another series of experiments found that the reaction-time for sensations of light varied from 0.251–0.308 to 0.128–0.168, according to the intensity of the stimulus in six degrees of strength. Reaction-time diminishes, within certain limits, as the length of the electric spark perceived increases.

Expectation shortens Reaction-time. — If a preceding signal, at a favorable interval, informs us that we are about to be called upon to react, the time necessary for reacting is diminished. The cerebral centres are thus put into that condition of sensitiveness to stimulation which makes their activity the promptest possible. Thus the interval necessary for perceiving the sound caused by a ball falling 25 ctm., which without signal was 0.253 sec., was reduced by a signal to 0.076 sec.; and when the fall was 5 ctm., the interval was reduced from 0.266 sec. to 0.175 sec. In order to secure such a result, however, the signal must not be distracting; the interval between it and the expected impression must be nearly constant, and not so long as to overstrain attention.

When the quality of the impression to be expected is known, but its intensity is unknown, the duration of reaction-time is increased. It is also greatly lengthened when the impression takes us off-guard, as it were; in such a case the reaction-time may reach 0.4–0.5 sec. Of course, it takes longer to react in an unnatural or unaccustomed way.

Finding of "Discernment-time." — Donders and his pupils were the first to examine the speed of the psychical processes (or "psychical reflexes," as one observer calls them; *i.e.* "reflexes with cognition of the excitant"), with a view to determine how long it requires to recognize one of two or more different perceptions of sense. To solve this problem they employed several methods, not all alike of unquestionable value and accuracy. All the methods reduce to this one; namely, to find the length of reaction-time when discernment without choice takes place, and subtract from it the simple reaction-time. This experimenter allotted to the development of a clear perception of sound, in his own case, about 0.039 sec.

A particular mode of determining the amount of time required for "apperception," or discernment, was proposed by Baxt; it was based upon the principle of inertia as applied to the senses, especially of sight. Let us suppose some image, which requires discernment for its interpretation (*e.g.* the image of a particular color, of a letter or word, or of a simple geometrical figure), to be thrown upon the retina, and this image succeeded after a brief interval by the image of a bright white disk; then, if the interval be too brief, the first image will be "quenched," as it were, by the second, and "apperception" will not take place. As might be expected, it was found in this way, that the "discernment-time," or "apperception-time," depends upon the complexity of the operations required. To recognize three letters at once required about half the time necessary to recognize five or six. With an interval of 0.0048 sec. between the two excitations, the perception of the first was reduced to scarcely a trace of a weak shimmer; with an interval of 0.0096 sec., letters appeared in the shimmer; one or two of which could be recognized when the interval increased to 0.0144. The discernment became clearer with an interval of 0.0192; at 0.0336 sec. four letters could be well recognized; and at 0.0432, five letters.

The method of Baxt does not, however, enable us to fix the absolute value of discernment-time, because it includes as an inextricable factor the amount of time used up in the peripheral nerves. Besides, we have no means of estimating to just what stage a psycho-physical process must have advanced, when it becomes impossible for a following strong impression to overwhelm it.

Two other observers (von Kries and Auerbach) have attempted to measure discernment-time by a method known as the "Donders' C-method." In the use of this method the subject of the experiment attempts to answer the question: How long time passes after the occurrence of a stimulation before I know the precise nature of the result in consciousness? by either reacting in a prescribed way, or else by refraining from reacting at all. It was assumed (probably incorrectly) that "will-time" is not involved in the decision to react or not to react. From the whole reaction-time, as involving the answer to the foregoing question, the simple reaction-time was subtracted; the remainder was held to be the time involved in discernment. By this method surprisingly small intervals were obtained: for example, for discernment of the direction of light, 0.011–0.017 sec.; for localization of sound, 0.015–0.077 sec.; for discernment between two colors, 0.012–0.034 sec.; etc.

The figures just given have been contested, both on account of the method employed and on account of the result obtained. It must be admitted that both method and result can be justified only on the supposition that we are trying to determine how promptly, under the influence of training and habit, one may learn to connect a prescribed movement with a particular form of sensuous impression. Under such circumstances the time required for strictly psycho-physical processes becomes reduced to a minimum, and "*discernment*" *as a conscious process of discrimination largely or wholly disappears.*

Still another method has, therefore, been employed for disentangling the elements of this complicated problem. In this method the subject of the experiment is warned *when* to expect one of two or more colors, but does not know *which one* to expect; he is left to his own judgment to determine, and to signal just when the act of discernment is completed. The mean discernment-time, as derived from a large number of experiments with two color-sensations, was fixed by this method at from 0.047 to 0.086 sec.

We may affirm, then, that the average amount of the interval occupied in discernment of a very simple character, under favorable circumstances, is not very different from that given by Donders. It varies, when there is no special designed complication of the conditions, from 0.03 sec., or even less, to nearly 0.1 sec. Recent experiments, in the dark and quiet, to find the whole reaction-time, including discernment, for different colors, report the following result: for red, 0.153–0.160 sec.; for blue, 0.156–0.164 sec.; for violet, 0.161–0.168 sec.

Several Causes that affect Discernment-time. — To discriminate the *intensities* of two sensations is a relatively lengthy process. For example, when requested to react upon the stronger only of two stimulations of the sense of touch, we require more time than to tell where we are touched. When reaction follows the weaker of two such stimulations, the discernment-time may rise to 0.069 sec. or 0.089 sec. In discerning between two simple tones of different pitch, reaction follows the one of higher pitch more promptly. In general, discernment-time diminishes as the pitch of the tone rises; for very high tones it nearly reaches the limit required for hearing the noise of the electric spark. This is due to the fact that some 15–20 vibrations are necessary in order to define the pitch of any tone. To localize a spark by indirect vision requires more time than by direct vision.

An apparently true and important difference has recently been detected between two equally normal methods of reacting when experimenting for discernment-time. In the first, the attention is concentrated upon receiving the expected sensation, and every tendency "to get the motion ready," as it were, is carefully avoided. In the second method, one does not think of the sensation, but concentrates the attention upon getting ready to move. The reaction in the extreme "motor" type is much prompter than in the sensory type, — in the proportion of about the following figures: 0.125, 0.137, 0.123 sec., to 0.223, 0.224, 0.230 sec.

Discernment-time increased by Number of Objects. — Every one knows that it takes longer — other things being equal — clearly to apprehend several objects than only one object. In trying to discern one of four colors the time of the corresponding psycho-physical processes is lengthened to as much as $\frac{1}{10}$ or even $\frac{2}{10}$ sec., and more. In apperceiving figures, however, it requires little longer to master three than one, but considerably longer to master four than three. The obvious reason for this is our habit of grasping numbers in periods of three each. Moreover, the discernment-time for the different letters varies somewhat remarkably; but the "legibility" or comparative accuracy of the quick discernment of the different letters varies still more.

Finding of "Will-time." — If we admit the accuracy of the conclusions reached as to simple reaction-time and "discernment-time" so called, it becomes comparatively easy to answer the following question: How long does it take, under different circumstances, to set free a voluntary impulse? The simple reaction-time (R) — or time required when the nature of the stimulus is known and the mode of reaction fixed the same for all cases — is first found. The reaction-time required to discern clearly one of two or more impressions, and to announce the fact in some way previously determined upon (*Rd*), is then found. Finally, the reaction-time is found for cases where there is involved, also, a *choice* of one of several ways of reacting, or a *choice* between reacting and not-reacting (*Rdw*). If *Rd–R* gives the discernment-time, *Rdw–Rd* will give "will-time."

Experimenting in this way, one observer found the mean interval, in the case of ten persons, required for the setting-free of definite reaction involving a choice between two possible courses, varied from 0.024 to 0.155 sec. If the choice were one of ten possible courses, — for example, the selection of one of the ten fingers with which to react on receiving the impression corresponding to that finger, — then the will-time reached 0.298–0.448 sec.

Individual Differences of Will-time. — If the curve of the variations in the time required for choice by different persons, under different conditions, be plotted, very interesting personal peculiarities manifest themselves. In general, these peculiarities are increased, as the complexity of the choice rises from one to five places; they are then diminished as the complexity rises to nine or ten places. It thus appears that men differ more in the speed with which they can choose one of two to five different courses, than one of nine or ten different courses.

A careful survey of the whole field of experiment and statistics shows that it is not possible, as yet, to analyze psycho-physical time into its elements, with a perfect confidence in our accuracy. By practice and by arranging all the conditions as favorably as possible, so-called "discernment-time" may be reduced almost to zero. That is to say, reaction-time, including what was once "discernment-time" and "will-time," *may* be diminished so as to be little or no greater than simple reaction-time. This accords with all our experience of the rate of speed possible to acquire in all movements of the body in skilled work or in the arts. The violin-player, for example, can learn to execute the complicated, discriminating movements of a trill, at sight, with as great speed as the most simple muscular movements excited from the cerebral centres.

Donders assigned almost precisely the same figures (0.036 sec.) to will-time as to discernment-time (0.039). Under comparable circumstances the two elements of psychophysical time are probably about the same. But there is other evidence to indicate that successive acts of discernment may attain a much higher rate of speed than is possible for successive acts of will.

Correspondence of Time Subjective and Objective. — How accurately does the estimated time-rate of consciousness correspond to the movement of time as measured by objective standards? Some general impressions on this point are derived from all our experience in psychometrical experiments. Thus one observer notes that, in a series of 39 reactions from eye to foot which actually had a mean interval of 0.184 sec., the reaction was *felt* to be "too slow" when it reached 0.199 sec., and pronounced "very good" when it fell below 0.178 sec. The mind therefore appreciated the actual interval to within about 0.01 sec.

There is abundant proof, however, that the speed and duration of our impressions, as estimated in consciousness, do not precisely correspond to the series of stimulations which act upon the organ of sense. By an ingenious device Wundt showed that one rarely hears a sound, for example, without some "positive" (placing it later than the real time) or "negative" (placing it earlier than the real time) displacement of it. When expecting a sound, and attempting to locate it in connection with a movement measured by the eye, the displacement is most frequently "negative"; that is, one believes one hears the sound too soon in the scale of visual indications.

Most Favorable Interval for Discernment. — The degree of accuracy attainable in estimating the length of intervals varies greatly for intervals of different lengths. There is one interval most favorable of all for exact estimation. Under ordinary circumstances our sensitiveness to minute differences of time is greatest at about 0.7–0.8 sec. (more precisely 0.71–0.755 sec.). This sensitiveness to minute differences of time is found by most observers to fall off quickly for intervals less than the most favorable, and more slowly for intervals greater than it; and this, with the result that times longer than the most favorable interval are estimated too small; those shorter, too large.

On applying the same method of experimenting to considerably longer intervals, very strange and somewhat conflicting results are obtained. One observer finds that the maxima of accuracy occur at the intervals which are multiples of the most favorable interval by some odd number; and the minima of accuracy at intervals which are multiples of the most favorable interval by some even number, — up to about 11.4 sec. Another observer finds that, with 0.7 sec. taken as the most favorable interval, the successive points of greatest accuracy are 2.8, 7.8, 9.3, 12, and 14.2 sec.; while those of least accuracy are 5, 8.5, 10, 12.8, and 15 sec. The former of these two authorities lays down the rule that minute intervals up to 0.7 sec. are exaggerated, those from this point to 5 sec. underestimated, and larger intervals exaggerated again. But another authority states that times shorter than 2 sec. are overestimated, and those longer than 4 sec. underestimated. It is obvious that individual peculiarities are likely to be of much influence in all such estimates; and that the entire subject requires further experiment with a view to place it upon a basis of broader induction.

Studies in Rhythm. — The time-rate of the most rapid and accurate discernment and volition may be profitably studied by determining the degree of accuracy with which successive sensations (like the clicks of clock-work), having a constant interval, can be counted. In this way it has been found that the most successful estimates cannot be perfectly sure of more than 2–4 clicks, when the interval between them is as brief as 0.0895 sec.; and, if this interval is diminished to 0.0523 sec., they cannot be sure of more than two clicks. The most successful estimates of 45 rapidly succeeding sensations were 42 and 43, with the longer interval; with the shorter interval, the best estimate was 32, the worst 17.

It appears then that, if the interval between the sensations counted is less than the shortest reaction-time between ear and tongue, some of the sensations drop out of consciousness. It appears also that the rate of sensations may far exceed the rate of motor impulses. We can hear much faster than we can count. And, in general, *the time-sense for series of mental phenomena is different for different classes of these phenomena.*

Reproduction of Composite Images. — In the discernment of one or more letters, numbers, or geometrical forms, association and the reproduction of mental images are, of course, involved. In fact, no *discernment* is possible without involving these mental processes. It is interesting and valuable, however, to determine how the reaction-time is increased by complicating these processes. This may easily be done by fixing the mean reaction-time, including these processes, and then subtracting the mean simple reaction-time. Thus the time required for apprehending single words has been fixed at from about 0.057 to about 0.177, for different persons.

All our familiar experiences concerning the differences among different individuals, with respect to promptness of apprehension and memory, concerning the conditions which lengthen or shorten these processes, etc., receive illustration from this field of experiment. The following numbers (which must be taken as approximate only) prove this statement.

	Sec.
Time needed to translate images into one's vernacular	0.477–0.545
Time needed to translate images into a foreign language	0.649–0.694
Time needed to translate short familiar words	0.199–0.258
Time needed to translate long and less frequent words	0.309–0.388
Time needed to remember a thing very well known	0.400–0.800
Time needed to remember with choice of several answers	0.222-1.042
Time needed to form simple and familiar associations	0.368–0.507
Time needed to form odd and unexpected associations	1.132-1.662
Time needed to form a simple and familiar judgment	0.180-1.127
Time needed to define a familiar word	0.391-2.023
Time needed to multiply two numbers	0.049–0.098

[In multiplying two numbers we, of course, call upon an extremely familiar and well-fixed association gained when we *learned* the multiplication table. In re-forming this association, however, the order of the numbers is not a matter of perfect indifference; reaction, as a rule, is quicker and more correct when the smaller number precedes. It is also somewhat quicker, in most cases, when the completion of the process is announced by touching a key with the finger than when it is announced by uttering a word — "reproduction with finger," instead of "reproduction with lip."]

The really astonishing thing about these statistics is the very great difference which exists in different cases with respect to versatility of memory and promptness of decision. This fact appears when, for example, the subject of the experiment is called upon to name some work of a well-known writer, some city in a particular country mentioned to him, etc. ("time needed to remember with choice of several answers"). The same thing is illustrated when he judges the length of a line shown to him, or defines "fame" as "a form of the ascription of praise," etc.

The Circuit of Consciousness. — Our estimates of the time-rate and duration of particular factors in the general field of consciousness depends, in part, upon the relation which they sustain to other factors in the same field, or even in the field which has just faded, as it were, out of consciousness. Thus *the general principle of the relativity of every state and of every factor of every complex state, of consciousness, is amply illustrated by experiments in psychometry.*

For example, when words are connected into sentences, it requires only about one-half as much time for each word (as 0.138 sec. to 0.484 sec.), to name them, as would be required for the same words when not thus connected. Single letters, too, can be named more rapidly when several of them are in the field of consciousness together. In nearly all cases as many as three letters, and in many cases even four or five, lend support, as it were, to each other. It has been calculated that the second letter in view shortens the time for apperception of the one in the "clear-spot" of vision by about $\frac{1}{40}$ sec.; even the fifth letter affects favorably the discernment of every other in the circuit of consciousness, to about the amount of $\frac{1}{200}$ sec.

Another application of the same principle arises in the determination of the number of impressions which can be comprised in one "field of consciousness." The old-fashioned and *a priori* theory of the soul decided that, on account of the soul's unity, it could have before it only one object at the same instant of time. Strangely enough, the most advanced school of associational theorists in England has maintained the same view. But experiment confirms the impression of the plain man's self-consciousness. He *believes* that he can attend — though with varying degrees of attentive perception — to several objects at the same time; and he *can* do what he believes he can.

To test this matter, let us suppose that the stroke of a pendulum, heard at regular intervals, is employed as the stimulus. Two series of successive strokes, separated by an interval, are compared without counting. How many impressions can such series contain and the comparison attain a high degree, or even a perfection, of accuracy? With the most favorable interval (0.2–0.3 sec.) between the successive impressions, and with strict attention, most persons can attain a high degree of accuracy with 10 or 12 impressions; some can hold in one field of consciousness no fewer than 15 or 16 impressions. If rhythmic grouping is permitted, the groups become as one perception, and 35 to 40 impressions are apprehensible in one field of consciousness. It is thought possible by some experimenters to apprehend a larger even number than odd number in the circuit of consciousness.

Or, again, let us try to determine the "grasp of consciousness" by showing from 4 to 15 short perpendicular lines for 0.01 sec., and then testing the accuracy of the perception possible of these groups of objects. By experimenting in this way it has been ascertained that most persons are infallible when groups containing not more than 4–6 lines are displayed.

Effect of Practice, Attention, and Fatigue. — Every one knows that practice and attention increase, and fatigue diminishes, the speed and the accuracy of our mental processes. Psychometry endeavors exactly to define the amount of these influences on reaction-time. Thus it has been found that practice reduces about one-third (0.080 sec. to 0.050; 0.098 sec. to 0.062, etc.) the "will-time" necessary for choice between two motions. By practice with five possible choices, the reaction-time fell, in one case, from 0.239 sec. to 0.083; in another case, where one of ten choices was required, the time was diminished from 0.358 to 0.094. The effect of practice on discernment-time is different. It may fall from as much as 0.117 sec. to as little as 0.021 sec. Discernment-time continues to decrease by practice after all diminution of simple reaction-time has ceased. Association-time is probably sensitive to practice in far less degree.

The effect of attention on reaction-time, and so on the psycho-physical processes involved, shows itself in a marked way when attention is disturbed. Thus the mean reaction-time, for a weak impression of sound, was increased by a disturbing noise from 0.189 to 0.313 sec.; and, for the sight of an electric spark, from 0.222 to 0.300 sec.

Fatigue and all depletion of nervous vigor tends to lengthen the period of reaction-time. The enervation of a hot summer's day, of a sleepless night, or following on bad news, has the same effect. In cases of idiocy, imbecility, and epilepsy, the length of psycho-physical time is increased. The simple reaction-time of a decrepit man of seventy-seven, taken from the almshouse, was found at first to be 0.9952 sec.; practice reduced it greatly, but not below 0.1866 sec. The appearance of sprightliness does not, however, always signify a speedy and accurate performance of the psycho-physical processes involved in reaction. Of two young men, Exner found one with a lively temperament to have a mean reaction-time of 0.3311 sec.; while the other, who had not a lively temperament, showed a reaction-time of only 0.1337.

Effect of Drugs, Hypnotism, etc. — The nature of the influence which alcohol has upon the speed of the psycho-physical processes is not quite clearly proved by experiment. Doubtless it differs greatly in dependence upon individual peculiarities, the quantity taken, and other more obscure conditions. Some observers find that a small quantity of wine slowly drunk decreases reaction-time; but a larger quantity, in several cases, increased it from 0.1904 to 0.2969 sec., although the subject of the experiment considered himself to be reacting with unusual promptness. A long series of recent experiments (some 8000 in all), to determine the effects of alcohol, ended in disappointment. They appear simply to have showed that this drug produces changes in reaction-time; but no constant effect dependent upon either quantity or kind could be detected.

Coffee, as a rule, decreases reaction-time, beginning its effect some 20–25 minutes after being taken and continuing it for about two hours. Experiment thus appears to confirm the influence of this drink to assist a certain speed and accuracy of psycho-physical processes; doubtless (it should be added) in those cases only where it is moderately used and produces no disturbance of digestion. Subcutaneous injections of morphine delay reaction-time; but the effect soon disappears unless the injection is repeated.

In summing up the results of experiment we should be warned against imagining that researches in psychometry explain the origin or nature of our ideas of time and of time-relations. To describe the rates and orders and durations of *the successive ideas* is a very different thing from explaining *the idea of succession.* Upon the origin and nature of this idea the so-called science of psychometry throws no light. Neither has it as yet succeeded in establishing new principles of peculiar value in psychology. We shall refer to some other of its more important relations when we come to speak of the psycho-physical character of attention and "acts of will" so-called.

One important thing to notice is that the different elements of psycho-physical time — such as discernment-time and will-time, and time necessary to come to consciousness, as it were — ordinarily overlap and blend with each other. But practice and attention tend in the direction of reducing them all to zero; so that the formerly complicated case comes, under these influences, to assume the psycho-physical character and duration of a case of simple reaction-time.

CHAPTER XVI.

FEELINGS, EMOTIONS, AND MOVEMENTS.

SINCE the beginning of serious attempts to establish a scientific psychology the consideration of the feelings and emotions has been unsatisfactory. The reasons for this fact, however, are partly unavoidable, for they lie in the nature of the case.

GENERAL THEORY OF THE FEELINGS.

Regarded from the introspective point of view, the phenomena of feeling are peculiarly obscure, indefinite, variable, and multiform. The very effort to subject them to a self-conscious examination immediately changes their entire character or wholly dissipates them. Their physiological conditions, also, are laid in equally obscure, rapidly and infinitely varied changes of the central organs of the nervous system. These conditions cannot be subjected to direct observation, or even — without great difficulty — to the more indirect methods of experimental analysis.

It is not surprising, then, to find that physiological psychology has little beyond certain more or less well-founded conjectures to offer respecting this department of investigation.

Essential Nature of Feeling. — Several fundamentally different views exist as to the essential nature of the mental phenomena for which we use the term "feeling." Indeed, the term itself is, as a rule, vaguely employed. Sometimes it means the sensation of pressure or of temperature localized in the skin (*e.g.* I *feel* the smoothness or coolness of the marble); sometimes it refers to sensation-complexes of an obscure and mixed origin and character (I *feel* tired, or well, or ill at ease); sometimes it designates what has been called more definitely, but uncouthly, "the pleasure-pain series"; sometimes it is employed for states of æsthetical or religious contemplation; and sometimes for that unique recognition which the mind gives to moral obligation (the feeling designated by the words "I ought"), etc.

In general, three theories must be recognized as to the essential Nature of Feeling. One of these emphasizes the underived and primary character of such states as merit this name. It claims that we can no more define what it is "to feel" than what it is to know. Indeed, it would seem to be, of the two, more unreasonable to require a definition of feeling. For to define is to use terms of ideation; but feeling, as such, is not ideation at all, and therefore its character cannot be stated in terms of ideation. The other two theories agree in regarding feeling as a secondary or derived activity of the mind. But one theory is physiological, and the other may be said to be "ideational," in its method of explanation. We shall pass these two theories briefly in review before returning to the first-mentioned and — as we believe — true theory of the essential nature of feeling.

Physiological Theories of Feeling. — These theories hold that those mental states which we call "*feelings*" *are*, essentially considered, *a peculiar consciousness of the condition of the nervous system.* That many states of feeling are directly dependent upon conditions which originate in the activities of the nervous elements; and that some nervous conditions are followed by painful, and others by pleasurable, feeling, there can be no doubt. It is very difficult, however, to bring all of the physiological conditions of feeling under any verifiable laws. And even, should we succeed in doing this, we should not define or express the essential nature of feeling.

Concord between Stimulus and Vital Activity. — The philosopher Lotze distinguished the feelings, as mental conditions involving pain or pleasure, from sensations as indifferent elements of our perception of things. Pleasurable feelings arise from coincidence, and painful from opposition, between the effects of the stimulus and any of those conditions to which the regular expression of the bodily or spiritual life is attached. "Feeling is, in general," says Lotze, "only the measure of the partial and momentary concord between the effect of the stimulus and the conditions of vital activity." It is impossible, however, to vindicate this principle as applying to all cases. The disagreeable character of the slightly bitter tonic, or the pleasurable sweetness of the deadly acetate of lead, cannot be declared, on scientific grounds, to signify even "a partial and momentary" discord or concord between stimulus and vital activity. Lotze, moreover, was far too keen a psychologist to suppose that, in laying down this principle, he was explaining feeling as a secondary form of consciousness. On the contrary, he himself expressly vindicated its right to be regarded as primitive.

Relation of Feeling to Quantity of Sensation. — It is a rule of wide application, that sufficient intensities of all forms of stimuli are productive of painful feeling. The same intensities are also, in general, antagonistic to the vital conditions of the organism. On the other hand, all intensities of some sensations of smell, taste, and hearing, are disagreeable to most persons. Nor can the disagreeable feelings of the higher intellectual, ethical, and æsthetical order be resolved into the consciousness of more stimulation of the nervous system than is good for its vital interests. The excessive and injurious stimulation of this system may be accompanied by a large amount of positive pleasure. Of course, in all these cases, attention, association, habit, and voluntary control, have much to do with determining the subjective state occasioned by the application of the various degrees of stimulus.

The dependence of pleasurable or painful quality (or tone) of feeling upon the amount of nervous excitement produced by the stimulus is most apparent in the case of the sensations. Sensations of moderate intensity are usually pleasurable; by "moderate" intensity we can scarcely fix anything more definitely than the actual point at which the minimum of painful feeling begins to follow an increase in stimulation. From this point the feeling of pain rises in intensity, as the intensity of the stimulus increases. But the curves which measure the increase of feeling and the increase of sensation do not correspond. According to Wundt, the maximum point of pleasure belonging to any sensation is the point where the sensation ceases to increase in simple proportion to the strength of the stimulus.

The view which regards painful feeling as the consciousness, so to speak, of the over-stimulation of the nervous organism, is compelled to deny that any sensation can be painful, *absolutely*, or irrespective of its intensity. Such denial contradicts tolerably obvious facts. As has been said, all degrees of some sensations are disagreeable to most persons. To point to the fact that some substances whose faint odor (as musk), or taste in moderate degree (as the bitter of hops) is agreeable, become intensely disagreeable when they excite more intense sensations, is not conclusive. The faint sensations are not the *same* sensations; their quality changes on increase of stimulus as truly as their quantity.

View of Bain and Grant Allen.—The English psychologist Bain has laid down the principle: "States of pleasure are connected with an increase, and states of pain with an abatement, of some, or all, of the vital functions." This principle has been criticised as "too vague" by Grant Allen, who would substitute for it the following: "Pleasure is the concomitant of the healthy action of any or all of the organs or members supplied with afferent cerebrospinal nerves, to an extent not exceeding the ordinary powers of reparation possessed by the system." But this statement (which, in principle, is similar to that of Lotze) seems to us much more vague than that which it is intended to replace. For what satisfactory standard, besides the cessation to produce the feeling of pleasure, shall measure the limit referred to in the words—"to an extent not exceeding the ordinary powers of reparation possessed by the system." Surely it requires a large credulity to believe that the powers of repair are exceeded whenever a robust man experiences a slightly disagreeable taste, or an unpleasant contrast of colors, or a bit of a twinge of conscience.

The Herbartian Theory of Feeling.—In strong contrast to all physiological theories stands the view which regards *the feelings as secondary conditions of mind, dependent on the relations of the ideas.* This view makes a sharp distinction between sensation and feeling. It classifies bodily pain as sensation and not as feeling. Hunger, thirst, weariness, shivering, etc., are sensations and not feelings. But sympathy, love, gratitude, reverence, admiration, etc., are feelings; since their content is of a mental rather than a physical order. The author of this view was the German philosopher, Herbart.

Feeling is, therefore, to be defined (so this school of psychologists hold) as the immediate consciousness of the rising and falling of one's power of ideating, as it were. It is not a primitive activity of mind; it is secondary and results from the reciprocal action of the ideas. If the ideas "inhibit" each other, the becoming conscious of the check or inhibition is unpleasant; if they "further" each other and readily fuse, the conscious feeling of this fact is pleasant. As the most prominent recent representative of this view teaches (namely, Volkmann von Volkmar): "Feeling is the immediate consciousness of the process of ideation itself as distinguished from the consciousness of this or that idea," and it is conditioned upon some resistance being offered to the process. The condition of the origin of a feeling is, then, the existence of two simultaneous opposed ideas; this co-existence occasions a state of "tension," and this state gives way as one idea triumphs over another.

The theory just described is interesting; it undoubtedly accounts for the conditions under which a large number of our pleasurable or painful feelings originate, — especially those of the higher intellectual and æsthetical order. But to refuse to speak of pleasurable and painful sensations and emotions as belonging to the realm of "feeling" at all, because they depend upon a physical basis, is to restrict the term unwarrantably. The Herbartian view, as a complete account of the nature of feeling, is disproved by all the considerations brought forward by the various forms of the physiological theories.

Feeling an Original and Underived Form of Consciousness. — We return then to our former declaration. *Feeling is a primitive and underived mode of the operation of conscious mind.* It can neither be defined by, nor deduced from, processes of sensation or ideation. To know what it is to feel, the highest intelligence would not of itself be capable. Such knowledge comes only from having felt. And feeling accompanies all mental experience, both that of sensation and that of the higher intellectual processes. Discrimination — which is an intellectual process — is, of course, involved in all recognition of the distinctions in quality of the different feelings, and of the characteristic tone of pleasure or pain which they all (or, in case we admit some "neutral" feelings, nearly all) possess. But the discrimination of quality involves the existence of quality to be discriminated. The feeling of pleasure we have in smelling a sweet rose, or in tasting a favorite dish, actually differs in *quality*, as well as in amount of pleasure characterizing its place in the so-called "pleasure-pain series," from the pleasure of doing a good deed; otherwise it could not be known as different.

Physical Basis of Feeling. — That many of our feelings depend immediately upon the condition of the nervous elements is beyond doubt. But are there *special* nervous elements — whether end-organs, nerve-fibres, or portions of the central organs — which must be excited in order to give rise to painful feelings? What is the peculiar nature of the excitation upon which the different feelings depend for their differences of quality? What is the characteristic change in the excitation that gives rise to the two kinds of "tone" which the feelings possess, — to pleasure and to pain? Physiological psychology can answer none of these questions with much confidence.

The prevalent view, hitherto, has probably been that the same nervous apparatus throughout, which on moderate excitement produces sensations of pressure or temperature, produces feelings of pain when irritated with increased intensity. This view would apparently be compelled to hold that muscular sensations have the same physical apparatus as feelings of muscular weariness or exhaustion; and that both hunger and cardialgia arise from excitation of the same nerves of the stomach.

Certain reasons exist, however, for doubting the complete identity of the nervous apparatus of painful and pleasurable feeling with that of the sensations with which such feeling is allied. Recent experiments seem to show clearly that the end-organs of pressure, temperature, and painful sensation, are not the same (see p. 237 f.). It is probable also that impulses resulting in pain travel by more or less distinct paths in the spinal cord (see p. 71 f.). In certain cases of disease the sensibility of the skin to pain is lost, while its sensibility to touch is not weakened. The reverse condition also sometimes occurs. In some diseased conditions a difference of as much as one or two seconds occurs in the time at which the sensations of contact and the feelings of pain (caused — for example — by the prick of a needle) arise in the mind. The painful feeling of being blinded, when the stimulus of light is too intense, seems to arise from simultaneous irritation of the *trigeminus*, rather than from the same irritation of the optic nerve which results in sensations of light.

The tendency of recent evidence seems to be, then, toward a somewhat complete separation of the nervous mechanism, whose excitement produces feelings of sensuous pain or pleasure, from that whose excitement results in the production of the sensations themselves. This evidence favors, so far as physiological theory can, the view of those psychologists who regard feeling as a primitive and underived form of conscious life.

As to the peculiar nature of the physiological action — whether in the end-organs, the nerve-tracts, or the nerve-centres — which results in conscious states of feeling, we have no information. Indeed, the facts just referred to are very difficult to reconcile with the rule which certainly covers a large number of cases, — namely, that increased intensity of stimulus, beyond a certain point, results in the production of painful sensations. This rule itself is undoubtedly due to inter-cerebral relations whose physical and physiological description science cannot give at present.

Classification of the Feelings. — It may be doubted whether the feelings, *as such and strictly speaking*, admit of classification. We have already shown that, in order to be subjected to the process of discrimination in self-consciousness, feelings must actually have specific or individual differences in consciousness. But in the attempt to use these differences, of which we are conscious, for purposes of classification, we are prevented in somewhat the same way as that in which we are prevented when attempting the classification of sensations of smell. The vague, varied, and shifting character of the phenomena, and their complete fusion with other factors of the mental life, seem to render their scientific study exceedingly difficult.

It is certain that no principle of classification can be suggested which undeniably applies to all the phenomena of feeling as such. If we divide the feelings into pleasurable and painful, we raise the question whether there are neutral or indifferent feelings. And if this question is settled negatively, and the completeness of such a twofold division is admitted, the division itself is of little value, because it does not serve to describe the variations among the feelings which belong to either group of the two in this "pleasure-pain series." Classifications resting upon anatomical and physiological differences are not, in fact, classifications of the *feelings*. The same thing is true of all divisions suggested as arising out of the relations in which the different feelings stand to the train of ideas.

Moreover, the different kinds of feeling shade into each other by almost imperceptible degrees. For example, the sensuous feelings cannot well be separated from the æsthetical, in such cases as the perception of the harmony of a musical chord, or of two adjacent colored surfaces. Even the feelings which we call moral are usually so combined with feelings having an obvious bodily basis and origin — especially when the resulting states of consciousness attain the strength of emotions — that a strict separation of the two becomes impossible. Love, for example, ordinarily involves elements of both a more purely sensuous and a more purely æsthetical and ethical sort.

Classes of Feelings. — It would seem then that we must be content to classify the feelings, not as such, but as dependent upon their more prominent connection with other classes of the mental activities. Even after adopting this principle of indirect classification, we find that the results are somewhat indefinite and unsatisfactory.

It follows that neither the "physiological" nor the "ideational" theory of feeling can furnish a sufficiently broad principle of division. This statement is true of Grant Allen's classification into (1) pleasures and pains of sensation and (2) so-called æsthetical feelings, — according as the activity of the end-organs in them is, or is not, "directly connected with life-serving function." It is equally true of the division, proposed by some followers of Herbart, into (1) such feelings as are dependent upon the form of the course of ideas, and (2) such as are conditioned by the content of the ideas.

The following division into four classes, according to the "natural organic variety" in the activities of the mind and the characteristic kinds and shades of feeling which accompany them, is as convenient and complete as any. Thus we derive (1) the *sensuous* feelings, or such as depend on the different qualities of the sensations of the special senses and of common feeling; (2) the *æsthetical* feelings, or those agreeable and disagreeable forms of consciousness which correspond to the mental images of perception and imagination, regarded as beautiful or not (the varieties of the feeling for beauty and its opposite); (3) the *intellectual* feelings, or those which correspond to the theoretic interests called out by the higher forms of thinking; (4) the *moral* feelings, or those which correspond to the relations of desire and will.

The development of the elementary feelings gives rise to a great variety of complex and mixed forms. So-called "higher feelings," or "feelings of feelings," unfold themselves; these are dependent upon the complex relations of society as organized in its existing forms.

In general, the different feelings are differently characterized by variations in content, rhythm, strength, and "tone" of pleasure or pain.

The Content of Feelings. — Some psychologists have denied that different feelings are distinguishable at all as respects their content. In other words, they hold that all feelings are to be resolved into a mere quantity (more or less) of pain or pleasure; that the "pleasure-pain series" *is* the entire characteristic of feeling, and that different feelings have their place in this series, as different amounts of the same quality of mental states. But such a view is plainly contradictory of our clearest self-consciousness, and renders all scientific description of the phenomena of feeling impossible. It is also virtually denied by all the language of feeling. We all *know that*, and *talk as though*, the feeling excited — for example — by a minor chord differs characteristically from that excited by a major; the feeling of a sensation of dark gray from that of a sensation of bright red; of avarice from patriotism; of anger from moral self-approbation.

The fact that those differences in quality which the feelings undoubtedly have are dependent upon differences in the conditions of the bodily organism, or upon the relations of the ideas in the mental train, does not abolish, but in part explains, the characteristic differences, in content, of the feelings themselves.

The Rhythm of Feelings. — Like all other mental phenomena, the feelings occur in time-form. The movement in the mental life is marked by rhythm or periodicity. This movement is determined rhythmically by changes occurring in the conditions of the nervous system or in the train of ideas. Sometimes the feeling seems to pass back and forth, by the zero-point in the "pleasure-pain series," between a slightly pronounced tone of pleasure and a slightly pronounced tone of pain. No very painful or very pleasant feelings are felt as a steady tension of body and mind.

Strength of Feelings. — Different states of the same kind of feeling, and different kinds of feelings, are unlike with respect to the amount of consciousness which they appropriate or absorb, as it were. The strength of feelings often undergoes a series of rhythmical changes. This is one proof that the condition of the end-organs and central organs of the nervous system determines the strength of feeling. But the course of the ideas is also of influence upon changes in strength. As the sensations or ideas become more clear or vivid, the feelings attached to them are likely to increase; as they become more obscure and feeble, the attached feelings die away in consciousness.

"Tone" of Feeling. — Nearly all feelings are — it is admitted by all observers — to be described as either agreeable or disagreeable. They can therefore be arranged, in accordance with their characteristic agreeable or disagreeable "tone," in a so-called "pleasure-pain series," as more or less on one side or the other of an indifference-point, or zero-point, in the scale. Whether there exist states of feeling that are situated at this zero-point — and, therefore, entitled to be called "neutral," — has been much disputed. Neutral or indifferent feelings were admitted by Reid, but denied by Hamilton. Recently in England a controversy has been carried on between Bain and others on this subject, — the former claiming, and the latter denying, that such feelings exist. Wundt attempts to argue for their existence in a somewhat *a priori* manner. Since we can plot the "pleasure-pain series" in a curve, part of which lies below, or on the pain-side, and part above, or on the pleasure-side, of the neutral line, this curve must cross the line at some point in its course. In other words, it is argued that one cannot admit that painful feelings shade *toward* pleasurable feelings, by less and less degrees of pain, and pleasurable feelings shade *away* from the least observably painful, by greater and greater degrees of pleasure, without admitting also that neutral feelings exist. The reply to such an argument is as follows: The actual relations of the qualities and quantities of states of consciousness cannot be accurately represented by the relations of the parts of material lines. The question, whether feelings exist which have not the slightest tone of either pleasure or pain can be answered only by a direct appeal to consciousness. This appeal we believe results in a negative answer.

Sensuous Feelings or Feelings of Sensation. — There are some feelings which are so connected and even fused with the sensations as to derive from the latter their name. According to the physiologist Stricker, information derived from the peripheral nerves consists of either sensations or feelings. But both physiologically and psychologically considered the two are different. In general, the stimulus must affect the end-organs of sense in order to give rise to a sensation; and, as we have already seen, sensations are built as factors, or elements, into the perceptions of external things. The physiological apparatus of feeling, even of the bodily sort, is probably to a considerable extent different from that of sensation. It is certain that the feelings have a peculiar self-reference, and a characteristic tone of pleasure or pain.

The question has been raised whether every sensation has some feeling, either agreeable or disagreeable, connected or fused with it in consciousness. This question must be carefully distinguished from the question previously raised; namely, as to whether every feeling belongs, or not, in the pleasure-pain series. We do not think it accords with the facts to declare that *every* sensation has some feeling. But that multitudes of our sensations are characteristically agreeable or disagreeable does not admit of doubt. In the case of the "geometrical senses" the feelings of pleasure or pain, which are fused with the sensations, are localized as the sensations themselves are localized. Indeed, we may speak of the complex object of self-consciousness as a painful (or agreeable) sensation, or as a painful (or agreeable) feeling. The burning coal, or the prick of a needle, is described as either a painful sensation, or a painful feeling, in the finger, — according as we wish to lay emphasis on the subjective side of the *suffering*, or on the objective side of the experience, as *bodily* suffering.

Character of "Common Feeling." — At all times in our lives an indefinite variety of nervous impulses is pouring in upon the cerebral centres from every part of the periphery of the body, and from the lower parts of the cerebro-spinal axis. Some of these impulses result from changes in the minute blood-vessels and other capillaries about the nerve-endings; some from the condition of the internal organs and the connections of the sympathetic system with the cerebro-spinal. Multitudes of impulses from all the organs of sense, too weak (under the existing conditions of the cerebral centres and of mental occupation) to excite consciousness, are constantly meeting and inhibiting or reinforcing each other in the brain. These all, together, result in a *mélange*, or obscure mixture, of bodily feelings, which serves as a sort of basis or background for the more clearly conscious activities of the mental life.

Sensations in themselves heterogeneous may be brought into a momentary relation by the partial identity of their source of excitation, and of the nervous connections within the central organs. What each of them contributes to the "common feeling" depends upon this relation; it also depends upon the relation sustained to the mind's course of ideas, to attention, to association, to habit, etc. For example, an obscure but massive feeling of being ill at ease, may, on our giving attention to it, resolve itself into sensations, with painful feelings attached, that localize themselves in the cramped chest or limbs, the tired organs of sense, the unhealthy digestive apparatus, etc. In conditions of ordinary bodily health our clearly localized sensations, perceptions, memory-images, and thoughts, are always accompanied by an undercurrent of "common feeling," — the "feeling of being in the body," as it is sometimes called.

Æsthetical Feelings in General. — It has already been said that it is difficult always to distinguish where the sensuous feelings end and those feelings which we may properly call "æsthetical" begin. Characteristic mixtures of feeling — many of them scarcely to be described — seem to be attached inseparably to many of our sensation-complexes. The feelings stirred by different musical chords and intervals and instruments might be instanced here. The feeling excited by the same tune, as played upon the violin and then upon the cornet, is not the same, irrespective of any known influence from association. Goethe called attention to the change in spiritual tone which harmonizes with the sensations awakened by looking through glasses of different colors. Few would deny that sober feeling characterizes sensations of black and dark gray, excitement goes with red, cheerfulness with light green, sensuousness with purple, cool quiet with dark blue, etc.

The distinctively æsthetical character of the feeling depends, however, upon our freeing ourselves from recognition of the sensuous basis. Pains and pleasures of the skin and muscles and interior organs are distinctly unæsthetical; those of smell and taste less so; those of hearing and sight less so still. Genuinely æsthetical feelings arise and develop in connection with perception and imagination; they therefore imply an intellectual origin and law of progress. They may be said to spring from the combination of the sensuous feelings under the ideal forms of space and time. Hearing is the principal sense for the combination of sensuous feelings so as to produce æsthetical feelings under time-form, and sight (the "geometrical sense") under space-form.

Æsthetical Feelings of the Ear. — Harmony and rhythm are the two principal forms of the æsthetical feelings of hearing. [The laws under which the sensation-complexes of consonance and dissonance are produced, have already been discussed (see p. 250 f.).] Harmony is colored by the way in which the clangs composing the harmony are held together. In the major chord all the clangs are firmly bound together by the fundamental clang, and a peculiar agreeable feeling of satisfaction is the result. In the minor chord the coincident overtone performs the same office less obviously, and the result is an æsthetical feeling tinged with dissatisfaction, or longing. Great intensity of the former kind of sensation-complexes may involve the pain of over-excitement; of the latter, the pain of unrest.

In musical time the periodicity of the acoustic sensation-complexes, of itself, stirs the æsthetical feelings. These regularly recurring impressions, which may have a different content of sound, are combined into series; certain members of the series are then accentuated. Thus the two fundamental kinds of musical time, or rhythm, are originated. These are "two-time" and "three-time"; and the feelings corresponding to each are markedly different. The funeral march produces the most pronounced form of the æsthetical feeling appropriate to two-time; the feeling of the waltz is the typical form produced by the musical rhythm of three-time. Thus *waves* of different forms of æsthetical feeling are made by music to rise and die away within the conscious soul.

Æsthetical Feelings of the Eye. — The pleasurable or painful impressions which are produced and fused with the visual sensation-complexes, if they are of distinctively æsthetical kind, are dependent upon the manner of the combination of these sensation-complexes, under the laws of the mechanism of vision with both eyes in motion. Beautiful visual form is determined largely by the course of the limiting lines. These lines, in order to arouse a pleasurable æsthetical feeling, must accommodate themselves to the laws of visual perception, as respects both their direction and their extent. Lines of slight curvature, and not too far continued in one direction, best comply with this requirement. But lines of very short curvature, or too far prolonged in one direction, do not produce a pleasing æsthetical effect. The mechanism of vision with both eyes in motion favors lines lying chiefly in the horizontal or the vertical direction. Long oblique lines are scarcely tolerable; since the eye can sweep (or construct) them only incompletely and with painful effort.

The æsthetical feeling for visual form is also determined by the way in which the form is constructed, through repetition and combination of similar or dissimilar shapes. In the horizontal direction the general rule is, that we expect symmetry in the arrangement of the simple parts; and pleasurable feeling arises at finding our expectation met. In the vertical direction, however, *a*symmetry is the right rule. These rules are dependent, in part, on our habit, and upon the consequent ease with which we master the details of a complex field of visual perception. Certain proportions between the whole and the parts, and between the connected parts of the whole, are favorable to the development of pleasurable æsthetical feeling. The so-called "golden diameter" — or rule, that the whole of a visual perception shall be to the larger part as the larger part is to the smaller part $(x+1 : x :: x : 1)$ — is claimed by some writers to hold true.

Intellectual Feelings. — It has already been seen that intellectual elements blend more and more with the causes which determine the character of our feelings, as we pass from the lower and more obviously sensuous to the higher and more distinctively æsthetical. The various activities of the mind, called intellectual, have their peculiar forms of pleasurable or painful feeling connected with them. As to the physical basis of these feelings we are much in the dark. It is obvious, however, that feeling is connected, in general, with all mental action. Pleasurable feeling arises where the time-rate of the ideas is moderate, and the movement of the mental train is accompanied by no severe demands upon the attention; painful feeling, where the time-rate is too slow or too hurried, and the movement of the mental train "tasks" (as we say) the powers of voluntary attention.

The more immediate dependence of the feelings on the relations of the ideas composing the mental train is a subject which has been treated with great skill and insight by those psychologists whose view was previously mentioned (see p. 385 f.). The discussion of this view — the view of Herbart and his followers — does not fall within the province of physiological psychology. What is called the "inhibition" and the "furtherance" of one idea by another doubtless has its physiological basis. This basis is controlled by the same laws of exhaustion and renewal of the nervous elements, and of the reciprocal dependence in which these elements stand toward each other, which we have seen to hold good for the entire nervous system. Indeed, all such laws have their highest and fullest exemplification in the case of the cerebral centres. When, for example, we are painfully trying to recall a forgotten name or date, what the Herbartian theory refers to as an "inhibition" of ideas, is perhaps, physiologically considered, a physical conflict between several inchoate molecular processes that are trying to master, as it were, a particular region of the brain. But science is as yet unable to work out these laws in detail.

Influence of Association. — From the point of view of consciousness, the influence of association over the character of our feelings is almost too well known to require remark. What physiological psychology can say as to the explanation of the association of ideas, in general, will be referred to elsewhere. It is enough at present to remark, that all kinds of feelings — sensuous, æsthetical, and intellectual — come, of course, under the principle of association. In this way all the more complex peculiarities of individuals, epochs, nationalities, etc., are best accounted for. The æsthetical feelings of the Highlander when he hears a bagpipe, of the citizen of the United States when he perceives a certain arrangement of red and blue colors on a background of white, of the Englishman when he hears the words "Her majesty," etc., all belong under this principle. Under the action of this principle, "feelings of feelings," the complex sentiments, and mental moods, are constituted. If we introduce the principle of heredity, and consider the whole subject from the evolutionary point of view, we shall doubtless conclude that many forms of feeling which now seem most primary and instinctive have really been acquired, under the laws of association and habit, in the developing life of the race. But all this would carry us too far from our somewhat restricted field.

THE EMOTIONS AND BODILY MOVEMENTS.

All the feelings, when their intensity as states of consciousness is greatly increased, are accompanied by marked changes in the condition and action of the bodily organs.

These changes in the bodily basis of the feelings react upon the character of the feelings themselves, and modify them most profoundly. Moreover, there are some kinds of feeling, whose characteristics are chiefly determined, in whatever degree they are manifested, by the condition and action of the bodily organs. "Affections" and "Emotions" so-called are developed from all forms of feeling when intensified to a sufficient degree. "Passions" are those states of feeling in which the very character of the feeling itself may be most appropriately described as the feeling of a deranged and over-excited bodily organism.

Characteristics of the Affections, Emotions, and Passions. — The consideration of all affectional or emotional forms of feeling involves these three important particulars: (1) The characteristic feeling which distinguishes each from the others; (2) the relation of the feeling to the chain of ideas, and the changes induced by the feeling in the movement of the ideas; and, especially, (3) its relations to the different bodily organs, and the reflex effect of the changes in these organs, both directly upon the feeling itself, and indirectly upon the feeling through the disturbance of the ideas.

All affections and passions may be considered, psychologically, as having their rise in some form of blind, instinctive impulse. Impulse becomes connected, in the development of experience, with perceptions and mental images of the objects that have excited or satisfied it. When this connection is established between the feeling, which as blind impulse takes no intellectual account of the object, and appropriate perceptions or mental images, the basis for an affection or emotion is laid.

Instinctive impulses are of two general classes, — those of attraction or craving, and those of repulsion. The natural germ of anger or hate, for example, is found in that blind, instinctive impulse of resistance, with its accompanying feeling of painful irritation, which all sudden and intense excitements of the nervous system arouse. In the child, or childish adult, anger bursts out against the inanimate object which causes pain or opposes freedom of movement. On the other hand, the affection of the child is nursed by the feeling of comfort it has in the arms, or at the breast, of the mother. By a growing variety of experiences, the impulses of attraction or repulsion become diversified into a number of affections and passions, characteristic of the different manifold relations in which the mind stands toward things and persons.

All emotional forms of feeling are characterized by abrupt and sudden changes in the character and time-course of the train of ideas. Any sudden, strong stimulus — as we all know — breaks in upon and destroys the steady and peaceful flow of mental life. It has sometimes been said that from feeling to emotion is a "leap." The tendency of any violent change of mental state is, then, to excite an "emotional" condition of the feelings, characterized by the peculiar kind of feeling which is appropriate to the particular character of the object or mental image which absorbs the state. All the emotions take men "off their guard." They "upset," "banish," "interrupt," the train of ideation. The members of this train, thus disturbed by the springing in upon them of emotion, become hurried, disordered, crowded, confused.

But, on the other hand, the effect of so marked and rapid a disturbance of the mental train reacts upon the emotion itself. The mind *feels* the disturbance of the ideas as a new emotion, or as an added characteristic of the former kind of emotion. The stream of conscious ideation being perturbed, the feeling of the perturbance is an emotional condition of the entire conscious life. Without doubt this mental confusion is indicative of an unusual molecular agitation, of a derangement of the circulation and psycho-physical chemistry, in the ideo- and sensory-motor centres of the cerebral hemispheres. But here again we know little or nothing of the particulars.

It is the remarkable and characteristic effect which such forms of feeling produce upon certain particular organs, that is the most noteworthy peculiarity of all affections, emotions, and passions. The influence of shame, fear, or anger, upon the vaso-motor system and the circulation of the blood, is well-known. But some persons grow pale, and some red, when angry. In experiment upon the lower animals, the curve which indicates the amount of blood-pressure is altered by the cerebral disturbance attending emotions of surprise, fear, or other similar excitement. Care, anxiety, strong love or hate, and all the passions, produce changes in the action of the capillary vessels, upon the secretions, the nutrition, etc.

The effect of some of these forms of feeling is chiefly to depress, and of others chiefly to over-excite, the action of the vital organs. Hence the division which Kant made of the affections, into "sthenic" or "asthenic." The former lame or kill by apoplexy, the latter may kill by laming the heart.

But this characteristic effect of the affections, emotions, and passions, upon the internal and vital organs of the body, reacts upon the feelings themselves. Of this effect, anger is a notable example. Under the influence of this passion, the teeth are set, the fists are clenched, the heart-beats quicken, the breathing becomes shallow, the limbs are stiffened or made to tremble, the organs of the abdomen are stirred, the creeping sensations of "goose-flesh" occur, the nostrils dilate. This mingling of sensations, with their characteristic feelings, and of so-called common feeling, forms the physical basis, as it were, of a rising tide of emotion. The tide subsides, of necessity, as the nervous exhaustion caused by over-excitement of the organism comes on. Indeed, the control of the passion may be indirectly undertaken by keeping down the influence of these sensuous feelings. Who can continue his rage, — with limp muscles, deliberate and regular breathing, relaxed jaws and fists, and a placid face?

It has already been shown that even the feelings called æsthetical or intellectual — and, we might add, ethical and religious — when they are aroused by mental images to a high degree of intensity, tend to assume an emotional character. They then partake of all the qualities which have just been described.

The Mental Moods. — Few things are more well-established in the popular estimate than the existence of so-called "moods" of the mind. By so vague a term we designate certain general differences in the average character of the complex states of feeling by which individuals are characterized. By the same term we also designate similar differences which characterize different periods, longer or shorter, in the life of the same individual.

We have spoken of the "mood" as a characteristic complex of feelings. This is because the influence of the sensations, perceptions, and train of ideas, upon the general "tone" of the mental life is to be considered as expressing itself in the mixture of feelings. The principal elements that determine any particular "mood" consist of ill-localized sensations arising from the visceral organs, accelerated or disturbed and depressed cerebral functions connected with the reproduction of the ideas, vague single feelings of the suppressed emotional, or the æsthetical or intellectual or ethical, type, etc. The passions and emotions, distinctly as such, run their course quickly, and give color to the personality chiefly by the frequency of their recurrence and the vehemence of their force while they last. But mental moods are slower in change and less strong in tone; they are characterized by affections and emotions of a low and lingering character, — pale and faded specimens of the type, as it were.

It will appear that mental "moods" — as respects their endurance in time, their complexity (quality of being *mixtures* of a vast number of obscure elements), and their dependence upon the constitution and functions of the entire bodily mechanism — stand midway between "temperaments" and the particular complex states of feeling which characterize our changing daily experience.

Another class of mental states, whose existence and nature are intimately connected with the direction of the bodily movements, consist of the so-called —

Feelings of Effort, or of Innervation. — The testimony of universal experience is perfectly clear to the fact that we know — it would be said by most persons, instinctively and immediately — the position and condition, as respects tension and strain, of our bodies and their individual members. But we have already seen (p. 316 f.) that this knowledge is the result of a development. It is of the nature of perception; and it is dependent upon a variety of localized sensation-complexes arising from the stimulation of skin, muscles, tendons, and joints. [Among these, the amount of influence exerted by the "muscular sensations" has been much disputed. It is not necessary, however, in this connection to repeat the arguments which have led us to assign to them a principal part, but not the whole, of the influence in constructing our perceptions of the bodily positions, strains, and movements.]

It is plain that the view previously taken assigns a peripheral origin to the so-called "feelings of effort." But the question arises whether their origin is wholly peripheral; whether, in fact, it is not partly, at least, of a central origin. The great physiologist Müller considered the nervous process which occasions the "feeling of effort" to be of purely central origin, and to consist of a discharge from the motor centre into the motor nerves. In other words, it is the *feeling of* the cerebral process which innervates the group of muscles, on occasion of a fiat of will. Wundt takes the same view, and regards this class of feelings, (which, in his opinion, differ only as respects quantity and not as respects quality,) as of chief importance in accounting for our experience of solid objects of sense and of whatever belongs to the inertia of matter in general.

The question, whether any elements of the compound "feeling of effort" are directly dependent upon the cerebral changes which immediately accompany an act of will, cannot be said to be experimentally settled. On the whole, however, the tendency is in our judgment to discredit the alleged proofs of such a central origin to this feeling. For it seems possible to account for most, if not all, of our experience of the different forms of "the feeling of effort," on the theory of the peripheral origin of the factors which compose it. For example, it has been claimed that, if we intensely make-believe to use any limb (let it be in pulling with the finger the imaginary trigger of a gun), but do not actually move it, we nevertheless have the consciousness of exerting effort. In reply it has been pointed out, that the feeling of effort in such cases is due to keeping the glottis tightly closed, while actively contracting the respiratory muscles. Let all these parts be carefully kept relaxed, and we cannot even imagine ourselves to be "making the effort" of using the limb.

It is further alleged, in evidence of the central origin of the feeling of effort, that persons afflicted with cortical paralysis can produce the consciousness of stress of will in the imaginary movement of the paralyzed limb. But in such a case this feeling is probably due to the condition of the joints and muscles. Even where the limb is wholly lamed, the feeling is actually produced, as a rule at least, by a movement or condition of squeezing and straining, produced in some sound but closely allied part of the body. Thus Vulpian noticed that his patients produced the feeling of effort *in* the lamed fist by *actually closing* the sound one. Another observer (Münsterberg) can allege no little experimental evidence, when he contends that involuntary contraction of the muscles of sight, tension of the scalp, etc., may be translated into the exertion of energy localized in different and distant parts of the body.

The case of the eye, when afflicted with partial paralysis of the *external rectus*, is almost classical. Patients having this form of paralysis localize the visual object too far out, on the side of the lamed eye. The argument is as follows: The patient *feels* that he has moved his eye much farther than he really has; he therefore localizes the object by this exaggerated feeling of effort. Since the peripheral result actually accomplished is a diminished effort, the feeling of the effort cannot originate from this result, but must have a central origin. In reply to this argument it has been pointed out (especially by Professor James) that the argument entirely neglects what goes on in the other and sound eye. The sound eye, unlike the lame one, continues its motion until the normal limit is reached, and the corresponding amount of peripheral strain produced. Since the two eyes operate as one instrument, the object is necessarily localized by the condition of the sound eye, no less than the lamed eye.

Testimony from persons who have suffered the amputation of limbs is ambiguous. A considerable proportion of such persons (perhaps about three quarters) report that they have had, for a longer or shorter time subsequent to the amputation, the feelings of position, strain, and movement, in the lost limb. The majority of those who have lost a leg or arm have the feeling *in* the foot or hand; but feel the parts intervening between these members and the stump, less vividly or not at all. Many who have lost a leg can "work" or "wriggle" their toes at will, — feeling both the effort and the movement; but *in most cases actual movements in the muscles of the stump can be detected.* It is probable that where such movements cannot be detected, the feeling of effort originates in the strain, or movement of other peripheral parts.

The connection of this discussion with a theory of the will, and with the dependence of acts of will upon a bodily basis, is obvious. The nature of the connection will be referred to in another place. It is pertinent here to conclude that, excluding what is purely "moral" (the choice and what is psychologically involved in it), the so-called "feeling of effort" is probably of peripheral origin. In fact, it should not be called *a feeling* at all. It is rather a mixture of sensation-complexes arising from the condition of the skin, muscles, tendons, and joints, and becoming localized (often in a very imperfect and illusory way) under the influence of the stronger factors in the perception, and in connection with the associated mental images and the accompanying "fiat of will."

How easily the true character of a complex perceptive process can be misapprehended by the conscious mind, when this process is dependent upon a mixture of obscure and indefinite sensations, is made apparent by facts like the following. A certain patient, who had complete anæsthesia and was wholly unable to discover unseen active or passive movements of his own body, could put forth the amount of effort to raise a given [illegible] in case he understood *by sight* its nat[illegible]erwise he could not even approximate[illegible] amount of muscular contraction [illegible] then, that in this patient's case [illegible] was estimated and controlled [illegible] without help from the so-called [illegible]

Kinds of Bodily Movements. — [illegible] our bodies and their members, considered in relation to the conscious mental processes, are of two kinds. These are (1) movements not dependent upon states of consciousness, and (2) movements that, for their explanation, require us to take account of antecedent states of consciousness. Of the former, again, two subdivisions may be made, — the *automatic* and the *reflex*. The nature and origin of both these forms of bodily movement have already been sufficiently discussed (Chapter VI.).

It should be noticed in this connection that sensations, ideas, and acts of will, which have to do with the movements of the body, constantly tend, as it were, in two directions, — either toward consciousness or out of it. The physical correlate of this statement is doubtless as follows: The nervous processes which stimulate to motion the different groups of muscles, rise and fall, with varying degrees of intensity, toward and away from the higher cerebral centres.

In the case of reflex movements, unaccompanied by those changes in consciousness that are called ideo-motor or voluntary-motor, either the "*arc*," around which the neural processes are completed, has its highest point below the cerebral hemispheres; or else the processes which rise into these hemispheres are relatively too weak to produce any sufficient effect within the centres concerned in such ideo-motor and voluntary-motor control of the muscles. In the case of unconscious automatic motion, the cerebral excitations which originate centrally — in changes of the blood-supply, etc. — do not involve, at least with sufficient intensity, these ideo-motor and voluntary-motor centres.

It is by means of these processes, in the two directions just described, that our learning and practice of all complicated movements of the body takes place. Such movements are those concerned in feats of dexterity and skill, in learning to handle tools, to play on musical instruments, etc.

Impulsive Movements. — Those changes of the position of the body and its members which involve states of consciousness may be divided into the *impulsive* and the *voluntary*. This distinction requires, however, such a variety of degrees that shade into each other as to be difficult of application. By an impulsive movement we understand one which, without a conscious fiat of will, follows upon certain states of ideation and of excited feeling. The *motif* for such a movement may be said to lie in the "impulse," or push, of feeling, which determines volition one way, without any proper choice.

Impulsive movements form the basis of the more distinctively voluntary. They are particularly prominent and influential in the early development of the mind. The neural processes, awakened in the brain of the infant by the action of various forms of stimulus upon the end-organs of sense, are themselves the stimuli, or awakeners, of states of consciousness. The tone of these states of consciousness is one of either pleasure or discomfort. By the natural mechanism of the body, certain forms of movement are connected with these states of feeling, which in general tend to enhance the feeling, if pleasurable, and to relieve it, if unpleasant. Thus certain bodily movements become connected with certain states of conscious feeling. More indirectly, the same movements become connected with the ideas and perceptions associated with the feelings. The reaction-time is shorter for the impulsive movements than for the voluntary; since "will-time" proper is dropped out (see p. 371 f.).

It is obvious, that the line between the automatic and the impulsive movements, in the earliest life of the child, cannot be drawn with confidence. And, inasmuch as the same thing is true of the automatic and the reflex movements, all three of these classes (reflex, automatic, and impulsive) are closely allied. It is impossible to say how much of the almost constant movement of an infant's limbs is reflex, how much automatic. It is equally impossible to decide, in all individual cases, between the reflex and the impulsive explanations of the grimaces of its face, its starting at sounds, etc. There is no doubt that the general order of development, however, is from the reflex and automatic to the impulsive.

Voluntary Movements. — Those changes of position in the body and its members, which are ordinarily called "*voluntary*," are so in reality only with respect to some of their elements. They involve other elements which are reflex, centrally co-ordinated, and impulsive. Nor must we understand "voluntary," in this connection, necessarily to imply conscious deliberation and choice, — an "act of free-will" in the fullest meaning of the words.

Voluntary movements are the highest class of movements, from the psycho-physical point of view, because they require for their completion the entire psycho-physical mechanism. They imply a development of both bodily and mental powers. They involve the five following conditions: (1) The possession of an *educated* reflex-motor mechanism, under the control of those centres of the brain that are connected with the phenomena of consciousness; (2) *impulses*, in the form of conscious feelings that have a tone of pleasure or pain and have become associated with, (3) *mental images* of movements and positions of the bodily members that experience has taught us are themselves connected with these pleasurable or painful states of feeling; (4) a conscious *fiat of will*, or order, as it were, for the realization of these mental images; and (5) a central nervous mechanism in which, as a matter of natural or acquired causation, the requisite motor impulses may arise, to go forth along their nerve-tracts to the groups of muscles concerned.

Careful study of these five groups of very complex conditions, both of nervous system and states of conscious mind, convinces us that the science of physiological psychology can deal in only a very fragmentary and doubtful way with most of the problems involved. Of the first, second, and fifth groups (Nos. (1), (2), and (5)) enough has already been said. Of the possibility of a psychophysical theory of the "fiat of will" (No. 4), as connected with choice, control of attention, freedom, etc., we shall speak more at length in another place. A few remarks may here be made concerning the "ideo-motor" character of this class of bodily changes (No. 3).

To *will* the movement of any particular group of muscles we must have had experience of the actual movement of that group; *i.e.* of the changes in the feeling of effort, in the perceptions and constitution of the entire mental life, which such particular movement involves. We can never "will" motion in general — motion, that is, of no particular member of the body, and without specific quality, direction, and velocity of motion. Each member, and each position of each member, and each kind, direction, and velocity of movement, has its own mental representatives in the ideation-processes of the mind. It is by these mental images that the particular "fiat of will" guides itself in each case. *We* can issue the requisite fiat of will by attention (whether forced or voluntary) to the appropriate ideo-motor images; but in no other way. Otherwise, the distinction between impulsive and voluntary movements is lost, and there is no accounting for the particular character of the movement which takes place.

Dependence of Perception on Movement. — Perception is a knowledge of "Things"; and all things are known to us as being external and having extension in space. Indeed, this is as true of our bodily members as it is of the remoter objects which we learn to know through them. Now it is this life of motion which gives reality to all *things*, whether they are regarded as parts of our bodies or are known as separable from our bodies. Were it not that the child is, from the beginning of its life, excited to movements — reflex, automatic, and impulsive — and so acquires an experience of feelings of effort and of mental images representative of all manner of movements, it could never gain a knowledge of a real world of things.

So true is this that we cannot even form the vivid mental image of anything, or of any change in the shape or position of anything, without evoking inchoate movements to serve, by the sensation-complexes which they occasion, as factors in our mental image. In the effort to form such an image of a chair or a table, for example, we institute a series of extremely subtle and delicate motor impulses of the eye or the hand, — of the senses with which we realize it. *The effort to image a solid object revives the appropriate inchoate motor impulses that are wont to control the active perception of that object.*

The Expressive Movements. — A certain appropriateness, or naturalness of connection, is recognized by every one as existing between some classes of ideas and feelings and those positions and movements of the body which *express* them. In this field comparative psychology and anthropology are particularly successful.

In explaining this class of movements Wundt has summarized the phenomena under the following three principles: — (1) the principle of the direct alteration of innervation. Strong emotions, with vivid ideas, exercise an immediate reaction on certain cerebral centres. This results in exciting some groups to action or increased tension; and other groups of muscles are lamed by the same process of central innervation. Hence the trembling of limbs and derangement of speech through fear; the reddening or paling which express anger, disgust, or shame, etc.

(2) The principle of the association of analogous sensations emphasizes such facts as imply that sensations having a common tone of feeling combine most readily and thus strengthen each other. In this manner, both mouth and nose express in company the disgust or pleasure of smells and tastes; the muscles combine with the skin to express certain sensations arising through irritation of the latter, etc.

(3) The principle of the relation of particular movements to particular perceptions of the senses is, of course, a principle of the broadest application. By gestures with the eyes, and head, and limbs, we indicate the ideas of extension and relation in space. Care, expectation, exultation, depression, throw the members of the body into expressive postures, which correspond to the perception of the objects exciting those feelings. It is under this principle that the psycho-physical science of the comic, of physiognomy, etc., brings a great number of facts.

Recent inquiries have elicited the interesting and important fact that, as a rule, the great actors actually have the feelings and ideas present in their consciousness, which their acting expresses with such wonderful results. Their power is the power to *put themselves* in the appropriate condition of mind, rather than the power merely to *act a*

CHAPTER XVII.

CONSCIOUSNESS, MEMORY, AND WILL.

INQUIRY into the physical basis of those mental processes which are ordinarily classed among the "higher" is, of course, peculiarly interesting; but it is, at the same time, peculiarly unproductive of well assured results. The psychology of these processes, as studied from the introspective point of view, has, on the other hand, a great comparative advantage. For it is *these* processes which best submit themselves to introspection; it is they which have been most carefully and successfully studied by the method of introspection. But the correlated cerebral processes — even if we admit without argument that such processes exist — are in precisely the opposite condition. The testimony of the most learned and cautious experts in physiology confirms the declaration, that such a thing as a definite and detailed science of the physical functions of the hemispheres of the brain does not exist.

We have previously discovered (see Chapter V.) that the so-called "general nerve-physiology" of the nerve-muscle machine is in a very incomplete condition. We have also seen that faint and doubtful guesses, conjectural modifications of general laws of the molecular physics of the nervous elements (the "laws" themselves being largely conjectural), comprise the answer which science can at present give as to the behavior of that vast complex of nerve-cells and nerve-fibres which constitutes the human brain.

The only course which physiological psychology can adopt in attempting to deal with mental phenomena of the so-called higher order is, then, the following: The *facts* of consciousness must be accepted on the authority of consciousness, as studied by the method of introspective analysis; and then we may cautiously *speculate* as to their probable physiological correlates, by extending the conjectures of general nerve-physiology to the cerebral hemispheres. This course will be adopted in the present chapter. If its results are not very complete and defensible throughout, the fault is to be charged to the account of the subject rather than its method of treatment.

Nothing which has just been said should be understood as detracting from the value of experiment in testing all theories proposed to account for the so-called "higher" mental phenomena. It must not be forgotten, however, that what the experiments themselves immediately give us is nothing other than more, and perhaps also novel, *mental* phenomena. The end of the thread which we securely hold in our hand always consists of observed data of consciousness. The other end, the correlated physiological brain-processes, is always hidden from our observation. Nay more; the theory of what it is that constitutes the peculiar nature of these processes is still in the stage of uncertain conjecture. And what it is that serves to make brain-processes a fit physical basis for the mental phenomena, or makes the conjectural changes of these processes fit to act as antecedents or causes of the different kinds of mental phenomena, is wholly unknown.

There are three topics under this general head to which our discussion, from lack of other trustworthy material, must be confined. These are the phenomena ordinarily called *consciousness;* and the special forms of consciousness called *memory* and *will.*

PSYCHO-PHYSICAL THEORY OF CONSCIOUSNESS.

The Nature of Consciousness. — From the point of view held by introspective psychology, consciousness cannot be defined. By the term "consciousness" we mean to indicate the most general fact of the existence, in some form, of sentient or mental life. But every actual expression of mental life is in some particular form; it is a "state" or "act" of consciousness. In other words, every actual consciousness defines itself by some *content*. For consciousness never actually *is* consciousness in general, — an activity or state that might be separated from all individual state or process of consciousness, without content, as it were.

Inasmuch, then, as consciousness is the condition of all internal experience whatever, we cannot deduce or explain its essential nature from particular forms of such experience.

Consciousness, or the general fact of having any form of sentient life in distinction from being unconscious (as in a dreamless sleep or "dead" swoon), must also be distinguished from *self*-consciousness. The latter is the conscious attribution of any particular so-called "state of consciousness" to the Ego, or subject of them all. That is, self-consciousness is a form of consciousness characterized chiefly by the nature of its object (the Ego), and by the peculiar feeling of interest which fuses with the apprehension of this object.

We have already spoken of a "circuit of consciousness" (p. 377), and of the number of objects which it can contain. Nothing is more certain or familiar in our experience with ourselves than the great variations, in respect to amount of energy, degrees of clearness, and — as it were — height of attainment, which characterize the different states of consciousness. To represent consciousness as an attenuated line, with no breadth or possible variation in breadth, is most misleading; and yet this form of representation has been the accepted one with a large number of English psychologists. If we are to assist our imaginations to a knowledge of the truth by such partially inapt figures of speech, it is better to represent the "field of consciousness" by a series of overlapping circles having a large possible variation in their diameters; or by what we see of change in a kaleidoscope when we turn it slowly before the eye.

The Physical Basis of Consciousness. — Little can be added on this point to what has already been said regarding the physical basis of the different forms of consciousness. It has been concluded that, in man's case, the cerebrum is probably the sole, as it is certainly the chief, "organ" of consciousness (see p. 179 f.). By this we can mean nothing intelligible, however, except this: that the constitution and molecular changes of the nervous matter of the cerebrum are the only immediate antecedents or concomitants of the phenomena of consciousness; and so that, whatever takes place in the body outside of the cerebrum has an effect upon consciousness only in case it gets itself represented, as it were, within that supreme organ.

A recent writer (Herzen) holds that the physical basis of consciousness rests on the biological law which conditions the activity of a tissue on its decomposition and ensuing regeneration. The intensity of consciousness, as a neural function, depends on the intensity of the decomposition of the brain tissue; and it is inversely as the ease and rapidity with which the inner work of one nerve-element is transmitted to another. This theory explains some facts. It does not appear, however, that the amount of the work of decomposition in the brain-tissue is a measure of the breadth, height, and depth, of the field of consciousness.

On grounds of general theory it is very probably true that the physical basis of any consciousness whatever rests upon a certain intensity, in the appropriate centres, reached by that unknown neural process for which these centres are, by constitution and habit, peculiarly fitted. But any consciousness is always some particular form of consciousness. Every particular form of consciousness may then be said to have its basis in a certain intensity of the neural processes peculiar to those centres, whose activity is correlated with that one form of consciousness.

Physical Conditions of Consciousness. — Among the known conditions of all conscious mental activity is the character and amount of the brain's blood-supply. To stop this supply results in putting an end for the time to all consciousness; to impede or corrupt it disturbs and depresses consciousness; to alter its character changes the character of consciousness.

Observation of man and the lower animals, and experiment on the animals by decapitation and otherwise, have shown that the condition of the brain is anæmic in sleep. When the amount and time-rate of the conscious mental processes are lowered, the amount of arterial blood drawn to the higher centres, and there used up, is diminished. Dr. Cappie has propounded the theory that the physical condition of consciousness, as distinguished from the unconsciousness of profound slumber, depends upon an excess of the pressure of the arterial circulation in the brain substance over the pressure of the venous circulation in the *pia mater*. The molecular agitation of the conscious mental processes draws the arterial blood through the capillary vessels, like the draught created by the burning of a fire.

Whatever particular theory may be held as to the precise nature of the physical basis and conditions of consciousness, thus much seems undoubtedly true. That peculiar kind of "work" which is known as the conjectural molecular agitation of the nervous substance of the higher cerebral centres is an indispensable condition, and in some way at least a rough measure, of the so-called activity or intensity of consciousness. Here again, however, must we refer to the very indefinite and figurative way in which we can use the terms "amount," "intensity," "measure," as applied to states of mind.

PSYCHO-PHYSICAL THEORIES OF MEMORY.

The mental phenomena which are grouped under the general term of "Memory" offer themselves, in a tempting way, to explanations derived from conjectural principles in "general nerve-physiology" and in the special physiology of the centres of the cerebrum. These phenomena are usually understood to imply three powers, or phases of one power of the mind. They are (1) retention, (2) reproduction, and (3) recognition. Of the three, only the first two seem to admit of even a conjectural physiological explanation; and it is doubtful whether these two, considered as separated (were that possible) from the third, are *mental* processes at all. "Recognition," however, is essentially *of* consciousness; it *is* mental and cannot be conceived of as having any physical representative or correlate.

Psychological Theories of "Retention." — We have just said that the "retention," which is commonly spoken of as necessary to the phenomena of memory, cannot be considered as a mental act. If we ask ourselves, Where is the idea or the perception I once had, between the time of original experience and the time of recall? — the answer must be: The "idea" or the "perception" is *nowhere*. It does not exist in any sense of the word, since the existence of an "idea" or "perception" consists solely in its being an act or state of conscious life.

But if we ask ourselves, What are those changes produced by stimulation in the substance of the brain, which constitute the physical basis of conscious acts of memory, under the laws of habit and association of ideas? — we ask a question which is perfectly intelligible, although its correct answer may not be obtainable. Three forms of the physiological theory of memory, considered as "retention," are possible. These are: (1) Memory depends upon a *movement* persisting in the brain; (2) it depends upon a certain residuum, of the nature of a "scar," or *fixed impression*, persisting in the brain; or (3) it depends upon a persistent *disposition*, or tendency to movement created in the brain. All such terms as the foregoing are probably used somewhat figuratively when applied to the brain substance; precisely what they fitly represent we do not know. But the third form of theory has most evidence in its favor. We shall, therefore, present the arguments in its behalf.

Fading of the Primary Image. — It is difficult to draw the line between the after-images of a sensory impression and the memory-images (strictly speaking) of the same impression. The thousands of faint impressions which enter into our daily life seem quickly to vanish without leaving even a trace behind. But that these impressions linger for a period near, or under, the "threshold of consciousness" can readily be shown. If we are called upon to direct attention upon them, to fixate and describe them, within a few seconds of their occurrence, we find it possible to do this. Some of them admit of such recall for a period of several minutes after their occurrence. But if not attentively "apperceived" within this brief time, such impressions usually fade away beyond all recall.

Relation of Retention to Time. — Let a line of given length be regarded, for a brief time, then removed, and after a varying interval the effort made to recall its image so as to compare it accurately with another line of nearly the same length. It will be found that the clearness of the memory-image of the visual line falls off quickly at first, then more slowly, and finally approximates a stationary condition. Let a tone of given pitch be sounded, and then, after a brief interval, a second tone of the same, or nearly the same, pitch. In such a case, according to the experiments of H. K. Wolfe, the judgment as based, in part, on the memory-image of the first tone, will be most accurate at an interval of about 2 seconds. For a longer period than 2 seconds, the curve of memory for pitch of tones falls off pretty regularly as the interval increases to between 10 and 20 seconds; then it is retarded or ceases to decline; and, further beyond, it falls off still more rapidly with increasing time.

That patient investigator, Ebbinghaus, found that the process of forgetting a series of "nonsense syllables" is rapid at first, and then slower afterwards. After an hour's time had elapsed, ½ the original work must be done to relearn the series; after 8 hours, ⅔. But after 1 day the impression retained about ⅓ its original strength; after 6 days, ¼; after 30 days, ⅕. This investigator concluded that the ratio of what is retained to what is forgotten is inversely as the logarithm of the time.

Persistence of Certain After-images.—In various cases of strong or repeated impressions, the complete or partial after-images recur persistently for a long time after the impressions have ceased. Prolonged work with the microscope causes the visual images seen in its focus to live "in the *fundus* of the eye"; so that, after several hours, shutting the eyes will make them reappear with great distinctness. Musicians, after musical seances or after giving instruction, sometimes hear the sounds repeated for days. After a journey on a railroad car, the rattle of the car may persist in the ears for a long time, as do the sensations whose impression arises in muscles, semi-circular canals, and other internal organs, after a journey by sea.

The Physical Basis of Retention. — Niepce de Saint-Victor has shown that luminous undulations may be "to some extent garnered up in a sheet of paper," ready to be revealed at the call of special reagents. A plate of dry collodion, after being briefly exposed to the sun's rays, retains for weeks in the darkness the effects of the indescribably delicate changes which have been wrought in it. The stimulation of certain reagents will revive the images latent in such a plate. The well-seasoned Cremona, which has been played upon by skilled hands, will reproduce the tones with superior sweetness and purity, on account of the secret molecular changes of which it has been made the subject by previous agitations from the bow of the violinist. These things, however, afford us only analogies for the physiological explanation of memory.

It is to distinctively *biological* facts and principles that we must look for the proper explanation of the mental phenomena which imply so-called "retention." The fundamental fact seems to be that the nerve-element — at least, the nerve-cell which is concerned in psychical processes (sometimes called the "psychic nerve-cell") — is modified in a permanent manner as an effect of its excitation. We have already considered many phenomena which imply this general fact. Such are the progressive establishment of functional centres in the spinal cord and brain of a young animal (for example, the new-born puppy), the phenomena of substitution in the localization of cerebral function, and, especially, many of the phenomena of aphasia. The same thing is implied in that acquired skill which results in "learning," as we say, so as without conscious judgment and choice to perform feats of dexterity and skill. Indeed, learning to walk, to talk, to sing, etc., implies the same principle. All habit, acquired in the control of the organism, tends to become habit of purely organic self-control.

Now the nervous system is a vast and complicated molecular mechanism, all coming under the general biological law. Moreover, we have to notice that the nerve-cells, modified as they are by repeated excitation, preserve and perpetuate the modification under the biological laws of the nutrition of living organisms. The exercise of any group of nerve-cells tends to procure their enlargement by appropriation of the nutriment brought to them in the blood-supply. And when these cells, thus enlarged and molecularly altered according to the character and amount of their exercise, multiply themselves, their offspring come under the general principle of heredity in its application to all living mechanisms.

The precise nature of the molecular modifications, which are thus perpetuated and propagated in the elements of the nervous system, is unknown. To speak of them as "persistent vibrations," that are "weaker echoes" of the nerve-commotions produced by the original stimulations, seems to us neither good physics nor sound physiological psychology. They are, rather, a specially complicated instance of the general biological principles of modified molecular constitution, increased nutrition, and inheritance of acquired characteristics.

The physical basis of memory, as retentive, is therefore laid in the habit, or acquired tendency, of the elements of the nervous system. This tendency has respect both to the individual elements and to the association of groups of these elements. Each element — speaking figuratively — may be considered as a minute area intersected by an indefinite number of curves of different directions and orders. Thus a molecular commotion in any such area may run out into the system along any one of innumerable curves. In every such small fragment "the whole curve slumbers."

Physiological Theories of Reproduction. — The nature of the physical basis of memory, considered as reproductive, is even more purely conjectural than that of memory considered as retentive. The most probable conjectures, however, are those which follow along the lines already indicated. A perpetuation of persistent and similar vibrations in the form of "weaker echoes" does not seem probable. The term, "dynamical associations," has been chosen by one writer (M. Ribot) to describe those tendencies to allied and combined action which become established in and between the different nerve-elements and cerebral centres.

Another writer (Professor Wm. James) has expressed his views as to the nature of the physical basis for the laws of association as follows: "The amount of activity at any given point in the brain cortex is the sum of the tendency of all other points to discharge into it, — such tendencies being proportionate (1) to the number of times the excitement of each other point may have coexisted with that of the point in question; (2) to the intensity of such excitements; and (3) to the absence of any rival locality or process functionally disconnected with the first point, into which the discharge might be diverted." "Every presentation," says another writer (Fouillée), "tends to associate with other presentations on account of the identity of their seat in the brain. . . . Contiguity in time links things only by means of a contiguity in extension of the brain. Thus are established in the nerve-paths, as on the railroads, junctions analogous to those where the switchman determines the course of the trains." [Is there, then, something to be said of a mental "switchman" determining the course of *these* trains of ideas?] But these, and all similar physiological theories of reproduction, seem to us far too simple to account for the phenomena as we have real experience of them,—including the control of association by attention, by æsthetical and ethical and other interests, and that peculiar accompanying condition of conscious memory called recognition.

Reproduction involves Forgetfulness. — "To live is to acquire and lose; life consists of dissolution as well as assimilation. Forgetfulness is dissolution." This is true whether we consider the subject from the mental or from the physiological point of view. If all the alterations of the intramolecular constitution of the nerve-cells were alike conserved and propagated, and if all the "dynamical associations" among the groups and centres composed of the cells were always alike stable, then no basis could exist for specific and characteristic reproduction of the memory-images.

In the phenomena of aphasia we see how temporary or permanent forgetfulness of classes of images, or of definite and particular images, may be due to functional or organic derangement of the cerebral centres. The same thing, in less degree, is shown in the loss of memory caused by disturbances of the blood-supply of the cerebral centres. Moreover, when a number of nerve-commotions, arising in different associated centres, flow together and inhibit each other in a certain area, loss of the memory of objects whose impressions are received in this area may be the result. Whatever interferes with the working of the so-called "dynamical associations" leads to confusion or forgetfulness of the memory-images. On the other hand, whatever quickens and multiplies the working of these associations results in acceleration and enlargement of the circuit of conscious memory-images.

Organ of Memory. — No tenable ground exists for speaking of a special organ or seat of memory. Every organ — indeed, every cerebral area and every psychic "nerve-cell"

— has its own memory. What Cardinal Newman once said of the psychical faculty is true of the organic basis: "There are a hundred memories as there are a hundred virtues." Every sense and every so-called faculty, so far as it comes under the biological laws applying to retention and reproduction at all, does so in the particular and definite associated areas where its physical basis is laid. There is sound reason, then, for speaking of a "memory of the ear," "memory of the eye," etc.

There is, then, no one place where alone memory is at home in the brain. Yet the memory of any perception of the senses, any complex state of feeling, or of ideation, involves a large number, not only of contiguous nerve-elements, but of more or less remotely allied centres of the brain. On this point again we might appeal to the phenomena of cerebral localization, — especially of aphasia and other pathological phenomena. This is true even of those cases where some particular date or name seems to slip away beyond the power of recall. For example, we have record of a patient who, after a fever, lost all knowledge of the letter F.

Complexity of the Mental Phenomena. — The laws of reproduction, or of the so-called association of ideas, have been the subject of curious and painstaking interest for hundreds of years. Probably no other subject in introspective psychology has received so much attention. In the attempt to simplify, the claim has repeatedly been made that they could all be reduced to a small number of principles, — perhaps even to a single law, like the "law of contiguity" or the "law of redintegration." We shall not enter this controverted field; it lies apart from the researches special to physiological psychology. In our judgment, however, the allied experimental and physiological researches indicate that the number of principles concerned in the reproduction of mental images must be greatly increased rather than diminished.

The researches of Ebbinghaus into the principles regulating his own power to learn and to remember series of "nonsense syllables" (see p. 421) led him to emphasize two pre-eminent sources of influence over the mental train of reproduced images. These were (1) changes in the concentration of attention; and (2) unconscious influence from theories and opinions. But if this be so, how immensely complex and profound must be the reasons which control the reproductive energy of the entire life of any individual mind! All the psychical, and all the biological, history of each individual expresses itself in every act of reproduction.

The great complexity of the phenomena of associated reproduction of mental images may be further illustrated by the answer to the following question: When a series *a b c d e f g* has been learned, does *a* recall *b*, and *b* recall *c*, and so on; or does *a* recall *b*, and tend also to recall *c*, *d*, and the rest? In other words, do the bonds of association which unite the memory-images extend below consciousness, as it were, though in a diminishing degree, to all the distant members once held together in the "circuit of consciousness"? The researches of Ebbinghaus answer this question affirmatively. *Learning once* a series of even 16 "nonsense syllables" *saves time* on attempting to relearn this series, *in whatever manner its members*, when relearned, *are related to each other.* The strength of association, as measured by this saving of time in relearning, is indicated by the following table: —

	Per cent.
Saving of time on relearning is, between contiguous members	33.3
Saving of time on relearning is, skipping one syllable	10.8
Saving of time on relearning is, skipping two syllables	7.0
Saving of time on relearning is, skipping three syllables	5.8
Saving of time on relearning is, skipping four syllables	3.3

Experiment shows also that the bonds of association extend backward — though with an inferior degree of strength — as well as forward. The same researches placed the saving of time in relearning, with inversion only, at 12.4 per cent.; with inversion and skipping of one syllable, at 5 per cent.

A reference to the fact that reaction-time is lengthened by increasing the complication and unusual character of the association processes, and shortened by practice and attention, reinforces the same conclusion. *In reviving established associations of ideas the entire mental history is involved.* But in forming new associations, especially, as well as also in reproducing the established ones, temperament, disposition, and conscious regard for utilitarian, ethical, and æsthetical interests, are potent influences.

The complexity of the phenomena called "mental" doubtless implies a somewhat corresponding complication of the brain-processes concerned in the reproduction of memory-images. In brief, the adult brain is a system of vastly intricate and interrelated molecular mechanisms. It has been, during its entire history, in the process of vital organization of these intricate interrelations. The particular brain-processes concerned in each act of reproduction all fall under the laws which control the general biological process of perpetual organization. The mental phenomena are a series of related "circuits of consciousness," — overlapping and fading into each other. The brain-processes are a succession of related nerve-commotions in centres contiguous and distant, — also overlapping and fading into each other.

The Psychical Act of Conscious Recognition. — The foregoing conjectures have to do with the explanation only of what is sometimes called an "organic memory." But so-called "organic memory" is a purely physical affair. It is utterly lacking in the power to suggest an explanation for that *conscious recognition* which is the peculiarity, and the peculiarly baffling mystery, of memory as a truly mental affair. Let us then consider what is involved when *I remember* this or that, — as we are wont to say.

The experience of consciousness is one of a constantly changing succession of states. The rise and fall of voluntary or involuntary attention, and the change in its direction, are accompanied by — rather are factors in — a constant shifting of the phases and circuit of consciousness. But of these shifting mental complexes, some bear a most peculiar mark. In their very nature they claim to reproduce distant and past phases or circuits of consciousness. They are, *sui generis*, "representative" of the past. But of *whose* past? for there is no circuit of consciousness, regarded as previously completed, that must not be attributed to some Ego, some mind. And there is no *memory*-image, claiming to represent such circuit of consciousness, that does not involve the conscious recognition of that particular image, as representative of *its own past*, by the same mind. These fundamental truths are not in the least affected by any actual or conceivable mistakes of memory. They simply describe the actual and indisputable peculiarity of that factor of conscious recognition which belongs, *sui generis*, to memory as a psychical act.

This peculiar and mysterious claim of the memory-image, to represent my past state (of perception, feeling, thought, etc.) is not, strictly speaking, verifiable by an act of comparison. Were I to attempt this, the perception of the object, renewed for purposes of comparison, would be a new perception, — another and different mental act; and the memory-image, revived for purposes of comparison, would be a new reproduction, involving the mystery of memory, as conscious recognition, in the same inexplicable form.

We cannot even conceive of the nature of a physiological process which would serve as an "explanation" in any sense of the word, for this characteristic of recognition, this self-appropriation as belonging to the past of the same Ego, or mind, which enters into all conscious memory. All that any physiological process could possibly explain, in case we knew its nature most completely, would be why I remember one thing rather than another — *granted the inexplicable power of the mind to remember* (consciously to recognize the present state as representative of its own past) *at all.* We repeat then the declaration of several years ago: "This power is a spiritual activity wholly *sui generis*, and incapable of being conceived of as flowing out of any physical condition or mode of energy whatever."

The connection of Attention, both voluntary and involuntary, with the phenomena of reproduction under the law of association, is manifest. The discussion of memory leads us therefore to consider, —

PSYCHO-PHYSICAL THEORIES OF WILL.

Several of the topics already discussed have included those phenomena in which so-called "acts of will" take part as factors. This is true of "psycho-physical reaction-time," and its lengthening or shortening according as it does or does not contain a choice between methods of reaction (see p. 371 f.). It is also especially true of the effect of voluntary attention upon the bodily movements, and upon the associated ideas which constitute the mental train (see p. 410 f.). From the very first, the experiments and theories of physiological psychology have been turned toward the consideration of the "will." The interest which such inquiries awaken, on account of their connection with problems in ethical philosophy and in the philosophy of religion, is too obvious to need more than a mere mention. Our general purpose, however, leads us to limit the discussion of the subject to those few points upon which some *experimental evidence*, however meagre, can be gathered from the department of science we are exploring.

General Physical Basis of Acts of Will. — If we use the general term "will" to describe all those mental phenomena which seem to secure the conscious direction or control of the bodily movements or of the mental train, we may make a probable assertion respecting their general physical basis. This basis is, especially, that power of *automatism* which is concentrated, so to speak, in the nerve-cells of the central nervous system, "Automatism," or the power of originating molecular changes which cannot be explained wholly by reference to the transmitted influence of external stimuli, belongs to all living protoplasm. It is on the basis of this fact that, as it is sometimes said, an amœba has "a will of its own."

The attempt has been repeatedly and persistently made to refer all the phenomena of living organisms to the order known as the "sensory-motor reflexes" (see p. 135 f.). Recently this attempt has been extended (particularly by Münsterberg and others) so as to include, without exception, all the highest psycho-physical processes. The principal justification of the thorough-going character of this attempt is our ignorance, and the desire to establish a single consistent theory for all cases of vital activity. But so long as physiology utterly fails to bring even the movements of a minute amœboid speck, or the behavior of the spinal cord of a decapitated frog, under any theory of "sensory-motor reflexes," we shall have (*a fortiori*) to acknowledge that the power of automatism belongs, in a peculiar way and high degree, to the cerebral centres.

No Special Organ of Will. — It has already been shown that "organic memory" is not a property of any one nervous centre, or group of centres, located in the brain. The same thing is true of that property of automatism in which we find the physical basis of will. Every centre of the nervous system which is capable of originating molecular changes in response to internal stimuli may be an organ of will so-called.

But an act of the will is always an act of some particular kind. There can be no volition to motion in general; but only a volition defined and limited to the movement of certain limbs, or of the trunk including the limbs, with a certain direction and degree of motion. Thus also every act of will, for the clearer "apperception" of some object in the circuit of consciousness, or for the control of the mental train, is necessarily limited and defined. And the physical basis of each act of will is laid in the appropriate physiological action of those centres of ideation, apperception and motion, which are concerned in that particular act of will. *Whenever an act of will takes place, then at the cerebral areas which are correlated with that particular act, the appropriate molecular changes arise in the "psychic nerve-cells."*

Kinds of Acts of Will. — From the point of view held by the student of ethics, it may seem incorrect and even absurd to deny freedom to any so-called "act of will." But from the point of view taken by physiological psychology the whole matter presents itself in a different light. We have already spoken of involuntary movements, that are not impulsive, and of forced acts of attention (see p. 408 f.). Both these phenomena imply "*uni-motived*" acts of will; that is, acts of will where there is no consciousness of acting freely or of exercising choice, but rather the contrary.

On the other hand, there are acts of will which involve an indefinite amount of antecedent deliberation, of weighing of reasons and motives, and final choice made with the clearest conviction that it is *our* responsible and free action. And between these two extremes there are all degrees of the rational and voluntary factors in different so-called "acts of will." A psychology, which is true to experience, is compelled to admit that what we prize as freedom of will is a matter of development, with an infinite variety of degrees. But what corresponding provision shall physiology suggest as necessary for those different processes that constitute the physical conditions of these phenomena? Only one answer seems to us defensible. It is this: a brain, developing under biological laws, and standing *in its peculiar relation to the unfolding of the life of consciousness*, with an infinite variety of ways of blending reflex sensory-motor and automatic processes in its allied centres.

Every so-called act of will is then the expression of the combination of several kinds of physiological processes, accomplished in the centres of the brain. These may include (1) sensory excitations coming from one or more of the end-organs of sense; (2) reciprocal excitement of allied cerebral centres in which the processes concerned in the appropriate perceptions and memory-images, with their accompanying tones of feeling, are taking place; (3) tentative and anticipatory motor impulses which mark the felt tendency to innervate particular groups of muscles; and, finally, (4) a certain automatic activity of particular nerve-centres under influence from the mental phenomena we call "choice,"—a thing which physiological science is wholly unable to explain but not competent to deny.

It is the resultant of these combining processes which represents on the physiological side, the complex conditions of the "so-called acts of will." These acts, as they appear in consciousness, are characterized by corresponding psychical characteristics. (1) They may be more or less mechanically controlled or forced by the intensity of sensation; (2) they may comprise a larger or smaller number of clear or confused perceptions and memory-images with differing intensities of different kinds and tones of feeling; (3) they may involve inchoate and anticipatory feelings of effort, or strain, that signify the drawing of attention, the rising in consciousness of a *nisus*, in one or more of several directions; (4) they may culminate, as it were, in a decided choice, with its accompanying and following conviction that *this act is*, in a peculiar and even unique manner, *our own*.

It is, of course, the factor of choice — No. (4) — which we designate as pre-eminently belonging to will. Choice is not, indeed, the whole of will. There can be no act of the mind as will, in the highest meaning of the words, which does not involve all the other above-mentioned sets of factors, both psychical and physiological. *Choice* is, however, the central and distinguishing factor of those acts which deserve, above all others, to be ascribed to the inner and independent life of the conscious mind. In the popular imagination — and we believe justly — choice implies a real influence of the mind over the body.

In terms of psycho-physical science: The existence of those states of consciousness, which are known to the subject of them as his *choice*, determines the arising of appropriate and correlated molecular changes in the higher and controlling centres of the brain. If this fact is ultimate and inexplicable, it is not, on that account, to be disputed as a fact. The evidence for this fact, from experimental and physiological psychology, is by no means small. We shall now present it — though only briefly and in part.

Dependence of Sensation and Perception on Will. — Many things which we clearly perceive, or intensely feel, or vividly remember or imagine, we cannot — as we say — "help" attending to. The sudden flashing of a light, or the passing of a bright object across the field of vision, the unexpected loud noise, the smells in the atmosphere, the tastes of our food, the sensations of the skin or internal organs, force themselves upon attention. Such phenomena tend to confirm the crude statement, recently renewed with manifold assertions and imposing array of argument, by Dr. Münsterberg: "The will is only a complex of sensations." The act of will, even in its highest form, is to be explained — this authority argues — as a sensory-motor process, by the ordinary presuppositions of natural science, and without the help of any immaterial principle.

But there are other phenomena which defy such easy-going attempts at solution of the mystery of body and mind. [The diminishing of discernment-time by voluntary attention has already been remarked (p. 371).] When, for example, we are attending to any sensation which is periodically repeated but very weak, fluctuations in its intensity constantly tend to occur. Thus a black radius on a white disk, when revolving, can be made to lengthen and shorten alternately. So the ticking of a watch can, by placing its distance aright, be made somewhat rhythmically to alternate between audible and inaudible. Now if attention, when directed to the sensation, is left to itself, as it were, it will vacillate with a regular periodicity — the explanation of which is not quite clear, and the length of which differs for different senses and under different circumstances. But voluntary and concentrated self-directed attention influences this period.

By voluntary attention we can intensify a sensation, and make clearer a perception or idea, in consciousness. We incline, indeed, to attend to the stronger of two excitations of sense; but, within certain limits, we can attend where we will. We incline to attend to objects lying in the point of regard of the visual field; but we can will to attend to objects lying in the outward portion of this field. By voluntary attention we can bring into clear consciousness the otherwise invisible double images. Some experimenters with the phenomena of "conflict of colors," when a green image is formed on one eye and a red on the other, can see either, or combine the two, at will.

The analysis of complex sensations or perceptions may also be performed at will. Voluntary concentration of attention is necessary for the musician to hear the overtones which combine with the fundamental tone to constitute a "clang." In mastering any complex visual object, the fixation and wandering of the point of regard is, to a certain extent, under the control of will. On waking gradually from sleep, our surroundings become more and more clearly defined to eye, ear, and skin, as the grade of voluntary attention in analysis and discernment rises. Voluntary concentration of attention, not infrequently, completely dispels the illusions of sense. In expectation of a particular sense-impression, concentrated voluntary attention may so affect the cerebral centres as to anticipate the expected perception; it may so intensify some weaker similar impression as to cause it to be mistaken for the expected impression.

In fact, all experience is full of similar facts. All language implies them. We cannot say, with emphasis, Listen! or Look! — instead of Did you hear or see? — without witnessing to the influence upon the organism of the mental act of choosing to attend to a particular sensation or perception.

Closely connected with, and indeed involved in, phenomena like the foregoing are the following facts, which bear witness to the influence of Will over the cerebral centres.

Dependence of Muscular Movement and Tension on Will. — No one is disposed to dispute that a large portion of our muscular movement, or muscular tension in the direction of movement, is reflexly or impulsively originated. In such cases there is no question as to the dependence of the cerebral centres as regards the psychical operation of conscious choice. It is undoubtedly also true that the muscles cannot be voluntarily innervated unless they have been previously called into action reflexly or impulsively, so as to furnish sensation-complexes and memory-images of such complexes, to serve as the objects for voluntary attention and choice (compare p. 411). We have also affirmed the opinion that the so-called feelings of effort and strain originate at the periphery of the body, in the conditions of skin, muscles, tendons, and joints. If we had only such phenomena of muscular movement to discuss, we might satisfy the demand for explanation by denying the influence of choice upon the cerebral centres and through them upon the muscles of the body.

But there is a large class of phenomena — both involved in ordinary experience and elicited by experiment — which plainly belong to another order. We can, within certain limits, decide "at will" — as we say — the speed, energy, rhythm, and magnitude of muscular contraction, and so the complexity and form of the resulting movements. This we do whenever we raise a weight, for example, by estimating in units of whatever standard of sense the character and amount of innervation of the muscles required to raise it. All deliberate and rational control of our bodily organs — and such control enters into the entire conscious life of apperception and representation — implies, and depends upon, the use of this power.

But we have also the unique and mysterious power of *inhibiting* the muscular movements which would otherwise be called forth by external and internal stimuli. On this point Gad has shown that the reflex stimulation of the eyelids with vapor of ammonia can be *voluntarily* inhibited; Brücke and others have demonstrated our power *at will*, to weaken the effect of the direct stimulation of a muscle by electricity; Eichhorst has called attention to the fact that the trembling of palsy can be partially suppressed, *if the subject choose.*

The terms "unique and mysterious" have just been applied to this power of inhibition at will. Recent experiments have seemed to disprove that this power consists in the innervation of muscles antagonistic to those called into action by the impulses reflexly originated. For there are muscles under the control of will that have no antagonistic muscles. The muscle used in accommodation of the eye is a typical instance of such an "autonomous" muscle. The facial nerve, which, of all the motor nerves, has the most direct anatomical connection with the higher motor centres, controls muscular action in the same way. What a "servant of the soul," for the voluntary and involuntary expression of the life of the soul, is here employed!

Now the reaction-time of inhibition, after brief practice, appears not to differ from that of direct impulse. On varying the tension and amplitude of the muscular excursion, the change in the "inhibition-time" follows closely upon the change in "impulse-time." It is a legitimate conclusion, then, that the paths in which the physiological basis of will runs, are identical for both impulsive and inhibitory volitions. It would seem that the place where the nerve-waves, which originate the inhibition, interfere with the nerve-waves which would otherwise originate the reflex-motor impulse, is the common "psycho-motor" centre. The direct voluntary control over the muscle, to modify or to diminish the amount of its contraction, is, therefore, the expression of the influence of the will over this "psycho-motor" centre.

Dependence of the Memory-images upon Will. — No part of our complex mental life appears to be so completely a matter of mechanism, conducted *before* the conscious mind rather than *by* it, as does the so-called association of ideas. This fact has already been made prominent by the phenomena of reaction-time (see p. 375 f.). But even in this part of mental life, the effect of voluntary attention and of conscious choice is unmistakable. This effect may, indeed, be so great as to impart to the memory-images the vividness of perceptions, by intensifying them and definitely localizing them anew in the organs by which their originals were formed. This fact connects this form of activity, springing from will, with the voluntary influence of sensation and perception.

Artists in kinds of art which involve a special susceptibility and activity of certain of the senses, are, of course, also gifted with a specialized creative and reproductive energy of imagination. Some classes of mental images tend to force themselves upon us all, whether *we will*, or not. But, on the other hand, we can all seize upon particular mental images, at will; and by concentrating attention upon them can clarify and strengthen them. The artist's weakness and his voluntary power are both special in these regards. Moreover, one can surrender one's self to a comparatively passive attitude before the train of associated ideas, — as when, for example, one indulges in reverie and day-dreaming. Or one (within certain limits) can say, to these ideas: Begone from consciousness! and one can enforce one's will by concentrating attention on objects of perception, or by turning into other lines the mental train.

Rhythm of Attention in Perception and Association. — We have already seen that weak sensations tend to rise and fall below the "threshold of consciousness" in a periodic way; in other words, they fluctuate rhythmically in consciousness. This period is different for different sensations; for example — as given by N. Lange — it is 3.4 sec. for optic vacillations, and not less than 4.0 sec., for acoustic. The fluctuations of sensation this observer attributes to fluctuations in attention dependent upon exhaustion of the cerebral centres. This explanation, so far as the assumption that voluntary attention directly influences the cerebral centres to exhausting molecular energy, we esteem correct beyond doubt. Although it has been shown recently (by Münsterberg) that peripheral changes also have a great, and even a determining influence, over the occurrence and the periodicity of these fluctuations.

During his experiments in learning and relearning "nonsense syllables" Ebbinghaus found indications of a remarkable rhythm in attention. There is, he thinks, a periodic oscillation of the mental susceptibility to intense concentration of attention, in which "the increasing fatigue seems to vary about a gradually shifting middle position." Thus, in 84 experiments with six 16-syllable series, the mean time for learning the 1st series was 191 sec.; for the 2d, 224 sec.; for the 3d, 206 sec.; for the 4th, 218 sec.; for the 5th, 210 sec.; for the 6th, 213 sec. Such a result can scarcely be due to anything else than a periodic exhaustion and recovery of the cerebral centres under the influence of attention as an act of will.

Phenomena like the foregoing are often appealed to in proof of the complete dependence of the so-called free choice to attend upon the condition of the nerve-centres of the brain. As to *a* dependence in this direction, there need be no doubt. But the primary and really astonishing fact is that the mind's choice to attend exhausts the cerebral centres by making them do intense and concentrated work. *The dependence of the activity of the "psycho-motor" centres upon the purely psychical phenomenon of voluntary choice to attend is the most important and marvellous of all psycho-physical facts.*

The Experiments of Münsterberg. — This investigator has already been quoted as holding that will is nothing but a "complex of sensations," a "definite grouping of sensations," etc. Now, from the point of view of self-consciousness nothing can well be more false and misleading than such statements as these. It is precisely this which we do *not* mean when, without having been prejudiced by so-called psycho-physical science (?), we candidly state our conscious experience. The words "I will," or "I choose," have a perfectly definite meaning as describing an activity of the mind; and this meaning is markedly different from that which we give to the words "I have this or that set of feelings or sensations."

Most students of physiological psychology who deny that the mind is capable of real choice, but affirm rather that what appears in consciousness as *its choice* is really a definite sensation-complex "dictated to it by the cunning conjurer, the brain," attempt to base their opinions on an induction from facts. This Dr. Münsterberg attempts. In our judgment — and, for the present, granting the accuracy of his experimental data — the attempt fails. His experiments show that the time of a free association is briefer than that of a limited association (the type of the latter being as follows: Given a general term, to name an instance under it). They show that a "question-answer association" (*e.g.* On what river is Cologne?) is also briefer than that of a limited association. But these facts may reasonably be held to be due to the general truth that it does *take time* to initiate those cerebral processes which are correlated with deliberate intelligent choice.

It may also be admitted that Münsterberg's experiments add strength to the opinion that, in complex associations, both the mental and the cerebral processes regularly overlap. "The mind is not a point through which each process must pass in turn, but is a place in which the most complex interactions have their play." And certainly the brain is very far from being a point. This admission is indicative of the exceedingly subtile and complex relations which exist between the different cerebral centres, and between these centres and the mind.

We know of no evidence from the experiments of physiological psychology which proves anything against the possibility of what consciousness testifies to, — namely, a real psychical phenomenon, unique and different from all mere definite content of sensation and mental images, which is, in the order of nature, a determining factor for the excitation of the "psycho-motor" areas of the brain.

Special Physiological Conditions of Choice.—What happens in the brain when, after two or more conflicting presentations of sense, or conflicting ideas, and a period of deliberation, one of them is made the object of choice? In answer to a similar question a celebrated physiologist responded some years since: "We know absolutely nothing." Of the physiological processes which accompany the mental preparation of the choice, it would seem that either one of two things may be true. The more intense of the conflicting processes may prevail over the others and gain possession — as it were — of the appropriate "psycho-motor centres"; or the several processes may persist and interpenetrate. An example of this kind of alternative may be taken from the phenomena of the "conflict of colors." But, looked at from the point of view of consciousness, it is obvious that the will, or choice of the mind, may decide a question of conflicting perceptions or ideas. What precise physiological process corresponds to this psychical act of choice, — the mental phenomenon of decision after deliberation? The same confession of ignorance quoted above seems to exhaust the subject.

We have seen that the effect of voluntary attention is most marked upon the cerebral centres. By it some of them appear to have their molecular energy relatively depressed; and others are relatively heightened. By it the entire mechanism of the brain may be called upon for a rapid conversion into kinetic form of the stored energy of its nerve-cells. Thus, under the influence of attention the entire cerebrum (and the different cerebral centres with varying relative degrees) is put into a condition of changed susceptibility to external and internal stimuli, as well as to the discharge of "psycho-motor" energy along the various efferent nerve-tracts. Concentrated voluntary attention implies a large amount of work in process of accomplishment, within the cerebral centres. The feelings of strain and exhaustion, the profuse sweating which often accompanies experiments in reaction-time, are in testimony on this point.

Choice is — as every one knows — followed by a sense of relief from strain; it is apparently significant of the subsidence of that condition of conflicting states of tension and nerve-commotion which has, before the consummation of choice, prevailed in certain cerebral areas. But, as has already been twice said, precisely what it is that is brought about by will (or the mind making a choice), physiological science cannot say. Nor does such science furnish the slightest valid ground for the assertion that the choice is not, what it appears in consciousness as being, — a psychical occurrence that determines the adjustment of physical relations between the parts of the bodily organs. This adjustment is, however, not primarily one of the visible and gross masses of this organism, but of the molecular conditions and activities of those "psycho-motor" areas which control these masses.

Physical Basis of the "Higher Powers." — We decline to enter upon the discussion of the question: What special molecular conditions and activities are correlated with the mental processes called "abstraction," "generalization," etc.; or with the higher æsthetical and ethical feelings and ideas; or with those norms of all rational life which philosophy has been wont to call the "intuitions" or the "categories" of the mind? Upon these subjects our ignorance is not only profound, but also — it would appear — hopeless. No other higher wisdom in this field is known to physiological psychology than that illustrated in the following quotation from Lotze: "For all the higher spiritual faculties, which consist in judgment of the relations of given conceptions, we neither know how empirically to demonstrate a definite bodily organ, nor should we know how to conceive precisely what, that is of any use, such an organ could contribute toward the solution of the problem — that is, the pronouncing of the judgment itself. It is conceivable, on the other hand, that these higher activities might presuppose the complete and clear representation of the content about which the judgment is to be passed, and, consequently also the undisturbed function of those organs which contribute, first, to perception by the senses; then to reproduction and combination with other perceptions; and, finally, to the appropriate attachment of feelings of value to each of them."

CHAPTER XVIII.

AGE, SEX, AND TEMPERAMENT.

THE relations between mental states and physiological conditions and activities, which have been thus far examined, are in general subject to sudden alterations. From moment to moment of our daily life the quantity, quality, time-order, and mental combination, of our sensations are dependent upon the amount, kind, rate, and conjunction or opposition of the stimuli. When, however, we consider the psycho-physical theories of memory and will, as well as of mental moods, we find more relations of a statical character established between mind and body.

There are certain relations of the mental phenomena to the physical basis which change their character very slowly, or do not change at all. One cannot alter one's sex, parentage, or race-inheritance. In the correlated development of the body and mind, as dependent upon the time of life, marked changes come, for the most part, only gradually. Here, however, epochs of change occur in both sets of characteristics, such as emphasize the dependence of the latter upon the former. A genuine and clearly marked "temperament" may be combated successfully; but the fact of the struggle reveals that firm possession of the seat of influence over mental life which certain obscure inherited physical traits customarily maintain.

It is these "statical" relations between the life of mind and its bodily basis which we now propose briefly to examine. The examination will only include the three points, of

Age, Sex, and Temperament. On all these subjects the collection of data involves an exploration of wide and uncertain fields. The entire investigation is, indeed, rather anthropological than strictly physiological or psychological in its nature. In both the physical and the psychical series there are necessarily many gaps and deficiencies. The conclusions — if such they can be called — must be received with this understanding.

RELATION OF MIND AND BODY DEPENDENT UPON AGE.

Prenatal Physical Development. — The growth of structure, and the unfolding of physiological function, in the unborn human being have been, more or less successfully, investigated by embryology. Yet this biological science gains most of its knowledge of the human fœtus from study of the lower animals. Certain large and elaborate organs, such as the lungs, the eyes, the ears, etc., are formed under morphological conditions and influences with which we are imperfectly acquainted, but without any corresponding psychical development.

The brain and the organs of sense, several weeks after birth, are apparently very little different from the same structures at birth. Yet a marked change in the mental life of the child has undoubtedly taken place. It is a fair conjecture, based upon grounds of "general nerve-physiology," that some corresponding change has taken place in the cerebral areas. Doubtless the molecular alterations and so-called "dynamical associations," which constitute the basis of the memory as retentive and reproductive, are chief factors in this cerebral change. It is certain that many of the structural and physiological changes which form the more intimate foundation for spiritual activities are secured only indirectly in the central organs through the cultivation given to these organs by the use of the end-organs of sense and motion. As Soltmann and others have found, stimulation of the motor areas of the brain of new-born animals does not produce the definitely localized movements usually obtained from the adult animal. The use of eye and hand, in their connected activity, by the new-born child educates his brain greatly in the few weeks just following birth. The dependence of mind and brain, preceding birth as well as afterwards, is presumably indirect and very complex.

Prenatal Psychical Development. — Concerning the psychology of the unborn human being we can speak with little confidence. Of sensations of smell, taste, hearing, and sight, there can be no question raised. The end-organs of these senses are developed at birth; but up to this time they have not been active so as to arouse the soul to the sensations of which they supply the required stimuli. Neither can those sensation-complexes, derived from the irritation of the skin, muscles, tendons, and joints, on which the perception of things extended and external depends, become highly developed before birth.

It is perhaps a reasonable conjecture which assigns to the psychical life of the unborn infant certain sensations of pressure and temperature, for the most part transient and disconnected, occasioned by the changing conditions and positions in the mother's womb. If we are to speak of *prenatal experience*, this low grade of consciousness can as little be accurately represented by any conscious state of the human adult as can the consciousness of the animals to which the structure and functions of the body of the fœtus, in succession, bear more or less of resemblance.

Dependence of Height on Age. — It has been estimated that the growth of the fœtus in length for the six months preceding birth is regular; and that it averages about 54 mm. a month. The mean length at birth of 100 infants, measured in Brussels, was found to be 0.501 m. (or about 19¾ in.) for boys, and 0.491 m. (or about 19⅓ in.) for girls. For 900 adults, in age from 19 to 30, the mean height was 1.6648–1.6841 m. The average height of 80 students at Cambridge, England, was 1.768 m. As is well known, the absolute height of adult man varies greatly in different regions and races, and under different conditions of climate, food, etc.

If we express the facts by the fraction of the whole height previously attained which the growth of each year attains, the figures are as follows: for the first year, about $\frac{2}{5}$; for the second, $\frac{1}{7}$; for the third, $\frac{1}{12}$; for the fourth, $\frac{1}{14}$; for the fifth, $\frac{1}{15}$; for the sixth, $\frac{1}{18}$, etc. From this time to the age of puberty the annual increase is nearly regular at about 56 mm. Shortly before or during the period of puberty, a sudden rise in the curve of growth occurs; but after this period the curve falls off until about the age of twenty-five, when maturity of height may be considered as attained. A very slight increase continues in most cases until about fifty, when a decrease — especially in old age — occurs.

The psychical life of perception and will is, of course, dependent to a large extent upon the height and gross bulk of the body. The knowledge of magnitudes and solidity of things, and the cultivation of the feelings of "Self" as a causal agency, as well as that "diremption" of experience which organizes all the world into "my sentient organism" as set over opposite to other "things," are, in a general way, dependent upon growth in height. The same remarks also apply to the following allied development.

Dependence of Weight on Age. — Like the height, the weight at birth also differs greatly according to parentage, prenatal conditions of nutrition, etc. The average weight of new-born infants, as ascertained in Brussels and also as given in the French "Dictionary of Medical Sciences," is about 3.055 kilo., or 6.735 lbs. avoirdupois. One year after birth the weight has, on the average, been tripled; in six years more it has been doubled again, and in thirteen years quadrupled. At about nineteen the mean weight of both sexes is about the same as that of old age. The maximum weight of the male is attained, as a rule, about forty; that of the female, somewhat later. At sixty the average weight, like the height, begins to diminish.

The psychical development is indirectly involved in the weight of the body as dependent upon age. This is particularly true of those sensations and cognate feelings which are connected with the poise and movement of the body, with its slower or more rapid adjustment to the changing relations of objects in space. The entire mental movement of the child is, in a measure, typified by the agility of its bodily movements. The "feelings of position," which belong to maturity of bodily size and weight have in middle life reached the culmination of precision and strength combined with speed. In all these regards the psychical life of old age suffers a decline which is visibly manifested in feebleness and slowness of bodily movements.

More indirectly still, and yet with great force and extent of application, does the same principle concern the moral and æsthetical feelings. The mind, acting as so-called will, is always, even in its highest forms of emotion and choice, interlocked with conditions that proceed directly from the conditions of the bodily basis. The *tempo* of life, and character of the strain to which its movement answers, are not the same for all its phases.

Relative Proportions among the Different Organs. — The size of the different bodily organs — both absolute and relative — varies greatly for the different ages of life; but their relative size remains nearly the same for all persons, not obviously deformed, of the same age. The most essential parts are least subject to any wide departures from the normal type. At birth the length of the head is about half that attained on complete development — or an average of about 111 mm. (4.37 in.). It reaches about 154 mm. by the end of the first year, and 178 by the end of the second. This growth of 62 mm. in two years exceeds all subsequent growth. The developed adult head is about, on the average, 228 mm. long, or ⅐ to ⅛ of the entire length of the body.

The facts just mentioned show that the increasing size of the head and of its contents of nervous matter, is correlated, not so much with absolute attainments of mental sort, as with mental exercise and growth in mental powers. The same truth appears in such measurements of the heads of those engaged in the work of students as have recently been conducted by Galton and others.

The development of back and legs and muscles, in the child, is relatively very different from that of the head. The back has at birth only about ⅓ its subsequent length; the arm, ¼; the leg, up to the place of its bifurcation, only about ⅕. The infant's foot (which will probably, if it be the foot of a civilized female, never again appear in its natural proportions) is about the same length as the head, — about ¼ of the body. The hand is about ⅑ of the length of the body. Unlike the head, the limbs grow rapidly after the second year. At the age of puberty they are greatly lengthened at the expense of their transverse proportions.

The following table shows the relative weight of the internal organs at birth and after maturity: —

ORGAN.	PERCENTAGE OF BODY-WEIGHT.		RATIO OF THE TWO, THE INFANT TAKEN AS 1.
	Infant at birth.	Adult.	
Skeleton	16.70	15.35	26
Muscles, etc.	23.40	43.10	28
Lungs	2.16	2.01	20
Heart	0.89	0.52	15
Skin	11.30	6.30	12
Eye	0.28	0.028	1.7
Brain	14.34	2.37	3.7

Dependence of Metabolism on Age.— To make the rapid growths of the first years, a great amount of food, representing a great amount of potential energy, must be converted into living tissue. This more rapid metabolism of the infant is partly demanded in order to keep up the normal temperature of the body, which is slightly higher (0.3°) than that of the adult. The infant's body also loses heat much faster on account of its extremely vascular skin. Most of the metabolism is directed, however, toward the construction of living tissue.

The heart of the infant is much larger, in relation to the entire body, than is the heart of the adult (see Table). The whole circuit of the circulatory system is traversed in about 12 seconds, while the time necessary in the case of the adult is about 22 seconds. The heart-beat is at first about 130–140 per minute,— falling off to about 110 in the second year, and to about 90 in the tenth. The respiration is about 35 per minute at first, 28 in the second year, and 26 in the fifth.

Everything in the infant indicates, therefore, a mobile and flexible condition of the bodily organs, with a relatively large development already secured to the most important parts of the nervous system. A scarcity of formed bodily and mental habits is indicated. The lines of habitual action of the mechanism have not as yet been marked out. Habits of mental sort, as connected with established dynamical associations among the nerve-elements and centres of the brain, are as yet unformed.

Psychical Development of the Infant. — The large size and advanced development of the brain and end-organs of sense at birth are indicative of mental potentialities rather than of the actual mental life. If we use the word "mental" to designate the phenomena of consciousness, it is difficult to trace the earliest *mental* development. The eyes of the child during the first days are seldom open for any length of time. Perception by sight implies associated and co-ordinated movement of the eyes, with the possibility of voluntary fixation or wandering of the point of regard. There appears to be considerable difference in the length of time after birth which is required to establish these necessary conditions. But the factors required in such development, as well as the stages by which it advances, have already been sufficiently discussed (see Chapter XIV.).

All newly born children, since there is no air in the tympanum previous to respiration, are deaf. Children differ greatly as respects the age at which they give sure tokens of having sensations of sound. The reflex excitability of the skin of the infant, in spite of its delicate character, is much inferior to that of the adult. It is only under gradual cultivation that it learns to respond in the maturer forms of this "geometrical sense." Taste and smell, considered as sensations void of all perceptive character, apparently belong to the first days of the infant's life.

After full maturity has been reached, or decline of the bodily powers has begun, the mental activities are less aggressive and acquisitive. But the period of more immediate dependence of these activities upon the lower sensory-motor apparatus has passed. The lines of both bodily and spiritual habit have become firmly drawn. Experience is stored; judgment has been trained, and is less liable to sudden assaults from impulse.

RELATIVE DEVELOPMENT OF THE SEXES.

While the dependence of the mental development upon the condition and growth of the bodily organs, as affected by age, is substantially the same for all, certain important differences separate the sexes.

Relative Height and Weight of the Sexes. — The curve of growth from birth onward runs somewhat differently for the male and female child. Before maturity the height of the two is about as 1 to 0.988; at maturity it is about as 1 to 0.937 or 16 to 15. The absolute height of the European adult male is 1.467–1.890 m. (about 4 ft. 11 in. to 6 ft. 4 in.); that of the female, 1.444–1.740 m. (or 4 ft. 10 in. to 5 ft. 10 in.). But at the age of sixteen the growth of the girl is as far advanced as that of the boy at eighteen or nineteen.

The relative weight of the two sexes does not follow exactly the same rule as their height. At birth the difference is about 0.6 lb. avoirdupois. But although the boy is born heavier, at twelve the two sexes have nearly the same average weight. Woman attains her maximum weight several years later than man. For normally formed and well-nourished men the limits are about 49.1–98.5 kilo. (108–217 lbs.); for women, 39.8–93.8 kilo. (98–207 lbs.).

Relative Proportions of the Bodily Members of the Sexes. — Even in early childhood sexual differences become observable, as respects the proportions of the bodily parts. The bony framework of the boy is more prominent and the outlines of the limbs indicate agile and strong movement. Roundness of limbs and amplitude of flesh cover the girl's framework. The formation of the pelvis in the two is unlike; and the centre of the line of length falls on a different part of the body. The chest of the adult male is more developed; his breathing is lower down; his rate of pulse and respiration less rapid. The length of his arms stretched out is about 1.045 of his height; of the female, it is only 1.015. The relative length of the legs is greater; and the circumferences of the various parts of his body are differently proportioned. His step is to hers as 1.157 to 1.000.

The average physical energy of which the male is capable is much the greater, — whether it be measured by lifting weights, by pressure with the hands, or other ways of producing mechanical effects. Before puberty this difference has been estimated as expressed by the ratio 3:2; afterward by the ratio 9:5, or even greater. The average boy of nine or ten years can support himself for some time with his hands; the girl cannot. The average man can lift some 154 kilo.; the woman scarcely half as much.

The metabolism of the female, whether measured by the respiratory or other excreta, is both absolutely and relatively less than that of the male. Her blood is less in quantity, of lighter specific gravity, and contains fewer red corpuscles.

More important differences concern the nervous systems of the two sexes. The weight of the female's brain, as compared with that of the male, is about as 1.272:1.424. The embryology of the two serves to show a difference in the development of the convolutions from the eighth month onward. The male is said to have, not only an absolutely greater cerebral surface, but also a relatively greater growth of the parts lying in front of the central fissure as compared with those lying behind.

Of the more definitely sexual peculiarities of organism, both stationary and periodic, and of their influence on the general physical and psychical development, it is unnecessary to speak.

Mental Differences of the Sexes. — It is obvious to any candid and intelligent observer that the foregoing differences in the bodily organism of the male and female involve most profound and far-reaching differences in the mental life. These bodily differences chiefly and primarily concern the life of sensation, emotion, and movement. But the mental life affected is fundamental and gives conditions to all the so-called "higher" intellectual and spiritual faculties.

The superior strength of the chest, shoulders, and hips of the male, and the fitness of the limbs and trunk for firm and swift movement, give him a superior consciousness of ease, elasticity, and security; both of posture and in changes of position. His sensations are more sharply discerned as respects qualitative content, less buried under the feeling with which sensation is fused. Decision, self-control, nicety and definiteness of judgment, as connected with the lower life of sensation and movement, undoubtedly belong to him in superior degree. Even more important sexual differences in the kind and amount of feeling — sensuous, æsthetical, and intellectual — are connected with the development of the organs characteristic of sex. The female is necessarily more under the control of feeling, with the exception of certain of the coarse appetites and passions; she is more subject to "moods."

The differences of the sexes in circulation, respiration, and metabolism, are connected with important differences in sentiment, emotion, and other forms of mental life. The female can better endure privation of air, food, and exercise; she is more patient and successful in the passive bearing of pain. But the larger mass of nervous matter, with its store of disposable energy, makes the male much more capable of all pursuits and achievements requiring such energy. And since all scientific, political, commercial, and nearly all artistic, pursuits and achievements require — particularly, and with increasing imperativeness in these days — the use of such energy, the average female cannot compete with the average male successfully upon this ground. The farther we advance in these pursuits and achievements, the more determinative does the constitutional difference become. It is undoubtedly the chief reason for the difference — now not less marked than ever — between the two sexes in the higher and the highest circles of such endeavor open to mankind.

We shall touch lightly upon the much disputed point of the spiritual characteristics of the sexes. Probably, to cite a few points from Lotze will sufficiently represent the true state of the case. This philosopher holds that woman adapts herself more easily to new conditions of life than does man, — because she is a mixture of the sanguine temperament and the sentimental stage; while varieties of education conceal more of her native qualities. It is characteristic of masculine philosophy to analyze phenomena; but women usually hate analysis. Masculine thought recognizes that what is great and beautiful in the world has its fixed mechanical conditions; masculine effort reverences general principles. The faith of woman is that the value of no principle is independent of concrete life; she is devout toward æsthetical completeness. The notions of the two even as regards spatial and mathematical relations are markedly different; the same thing is true as to their perceptions of the nature of the concrete realizations of the ideas of space and time.

THE THEORY OF TEMPERAMENTS.

Few impressions are more firmly fixed than this, that different individuals (at least among the more highly civilized peoples) are possessed of different *natural* "dispositions." The term "natural" expresses the current conviction that the foundation of their differences is innate and inherited, rather than the result of training and environment. Experience shows that a so-called "disposition" generally maintains itself under great alterations in circumstances, and against effort, to the close of the individual's life. Where it appears to be greatly modified, such modification is usually made at the expense of greater energy than is required even to break firmly acquired habits. Upon such patent facts the theory of "Temperaments" is based.

Kinds of Temperament. — The number 4 has been chosen most often to express the fundamental classes of temperaments. It is doubtless true that this number corresponds particularly well to the facts. On the other hand, no strictly scientific induction can be made, either as to the classification of temperaments, or as to the physiological basis upon which differences of temperament rest. The best obtainable treatment of the subject is, therefore, a mixture of keen general observation, shrewd conjecture, and speculation in the uncertain realm of psycho-physical theory.

A writer of nearly a half century since (Dr. Leopold George) would define the four temperaments by the interior relation which exists between perception and the affections of the mind. Thus, for example, the greater the mind's wakefulness to impressions, the greater is also its susceptibility to the feelings of pleasure and pain which are attached to the impressions. Hence the sanguine temperament, which is distinguished by peculiar strength in this interior relation. This theory is extended by its author so as to apply to the different periods of life and to different races of men.

Modern psychology is inclined to approach the subject of temperament from the physiological and biological points of view. In this way it is rendered more cautious: it can scarcely, however, be said to have added much to the definiteness of our verifiable knowledge.

Wundt's Classification of Temperaments. — The four-fold division of temperaments is adopted by this writer on the ground that, in every individual, there must be a certain combination of the two factors of strength and speed in that change which all mental processes undergo. The affections of the mind are therefore classifiable as either strong and quick, or strong and slow; or else as weak and quick, or weak and slow. By crossing these two principles of division the following scheme is derived:

	Strong.	Weak.
Quick	"Choleric"	"Sanguine."
Slow	"Melancholic"	"Phlegmatic."

The quick temperaments are directed rather toward the present, the slow toward the future. The quick require additional strength, the weak additional time, in order to achieve the largest amount of work possible for them. The choleric and phlegmatic are temperaments, with respect to action; the sanguine and melancholic are temperaments, with respect to feeling.

Wundt adds the following practical suggestion: "One should be sanguine amid the petty sufferings and joys of daily life, melancholic in the more serious hours of life's more important events, choleric toward impressions that fetter one's profounder interests, phlegmatic in the execution of the resolves that have been reached."

Lotze's Classification of Temperament. — By the term "temperaments" Lotze understands: "(1) The differences, in kind and degree, of excitability for external impressions; (2) the greater or less extent to which the ideas excited reproduce others; (3) the rapidity with which the ideas vary; (4) the strength with which feelings of pleasure and pain are associated with the ideas; (5) finally, the ease with which external actions associate with these inner states themselves." This authority also adopts the fourfold division of temperaments.

The *sanguine* temperament Lotze holds to be distinguished by great rapidity of change and lively excitability. It indicates an excess of sensitiveness to all external stimuli, and of capacity for reciprocal excitement among the different psychical states. For the temperament usually called "melancholic" he would substitute the term *sentimental*. This temperament is distinguished "by special receptivity for the feeling of the value of all possible relations"; but is indifferent toward bare matter of fact. It implies a lively appreciation of harmony and discord, great variety of æsthetical feeling and imaginative activity,— often with theoretical vagueness, ready yielding of the sense of duty to inclination, and dislike of hard work.

The *choleric* temperament is marked by "one-sided receptivity and great energy in single directions." It implies diminished susceptibility to excitement, but increased force and endurance in reaction when once the feeling has been aroused. Its best effect is steadiness of character; but its uncomely effect may be an obstinate and narrow perseverance in a path once entered upon, even when reasons exist for deviating from or abandoning it. Finally, the *phlegmatic* temperament is distinguished by slightly varied and slow, but not necessarily weak, reäctions.

Physical Basis of Temperament.—Nothing definite is known as to the physiological grounds on which rests the distinction of temperaments. The influence of abnormal bodily conditions, and of certain diseases, to produce or alter the disposition in a manner resembling temperament would seem to indicate that the original constitution of the brain is not the primary determining factor. The susceptibility of the end-organs of sense to external stimuli, and the strength of the resulting reactions in the form of common feeling, as well as the constitution of the visceral organs and the coloring they impart to every form of feeling, appear to be of prime importance.

Many authorities, not without a show of reasons, assign the different temperaments to the four main periods of life as distinctive of them, — the sanguine of childhood, the sentimental of youth, the choleric of maturity, the phlegmatic of old age. The fact that different periods of life are apt to be characterized by a predominance of one of the four temperaments is not an argument against the physical nature of the basis of temperament. For changes in the nature, speed, and strength of the reactions derived from the end-organs, and from the internal organs of the trunk, necessarily accompany the early development, the maturing, and the decay of the bodily powers. These things cannot fail, of course, to have a great though indirect influence upon the cerebral centres.

Characteristics of Different Races. — The theory of temperaments has been applied to different peoples, with more or less of success. For example, Dr. George would characterize the French as sanguine, the English as melancholic, the Spanish and Italians as choleric, the Germans as phlegmatic. More generally still, the Caucasian race is sanguine; the Mongolian melancholic; the Negro phlegmatic; the Malayan choleric. There seems little doubt that temperamental characteristics are more marked among the civilized races; if, indeed, they exist at all in any true sense of the word, among the savage and lower uncivilized races. It must be acknowledged, moreover, that the whole matter of such an application of the theory does not admit of a strictly scientific discussion and presentation.

In the more obvious external characteristics the different races of men vary greatly. Such characteristics are influenced, to a considerable but unknown extent, by soil, climate, food-supply, and prevalent manner of living; but they are developed under the general laws of heredity and variability as applied to the particular case of man. It is in the special features of height, weight, and relative form rather than size of the organs, that these characteristic differences chiefly consist. "The real differences which the races present," says an authority on this subject (Quetelet), "appertain to characteristics which the eye seizes better than the compasses; in order to establish them firmly, an appreciation of minute differences is required, and a tact that presupposes a long experience in such researches. One can see the difficulties with which phrenologists meet in making numerical estimates of the characteristics of the skull; nothing precise can be formulated in this regard."

Upon the general subject of individual and race characistics it remains only to add that "pure" cases of any of the four or more recognized varieties of temperament are comparatively rare. Here, as in other similar subjects, the lines which science attempts to draw are, in nature, crossed and confused. Mixed temperaments abound among the individuals of any civilized people; and no race exists that does not contain all kinds of temperaments and so overlap, as it were, the boundaries of all the other races — even those from which its average is most widely separated.

CHAPTER XIX.

CONNECTION OF BODY AND MIND.

We have thus far been studying certain groups of relations which exist between the structure and activity of the nervous mechanism and the phenomena called "mental," or phenomena of "consciousness." These relations may be summarized, with a fair amount of accuracy and completeness, under the following five heads.

1. *The quality and intensity of the sense-element in our experience is related to the condition of the nervous system as acted on by its appropriate stimuli.* The true state of the case with respect to these relations is, indeed, never to be represented by considering this sense-element as though it consisted merely of passive impressions dependent upon the kind and degree of the action which the stimuli exert. The same element is also dependent upon the habits and the present condition of the mind, at the time the stimulating effect of the excited sensorium is realized in consciousness. Mental habits and mental condition are, in turn, related to the "dynamical associations" and present occupation, as it were, of the cerebral centres at the time when the mental phenomena occur.

The entire sense-element — the various kinds and degrees of sensations — is a forthputting, a characteristic mode of the reaction, of the mind. Moreover, many of the phenomena which belong under this group of relations, and especially the marked effect of attention upon the sense-element itself, prevent us from regarding the relations as simple and one-sided. The mental state which is apparently most simple and passive is really a complex and characteristic activity of the subject of all mental states, — namely, of the mind.

2. *The synthesis of our conscious experiences is related to the combination in the cerebral centres of the impressions, made from whatever source, upon the nervous organism.* That the number, form, order, and time-rate of our mental states depend upon the number, kind, order, and time-rate of the separate excitations which are combined in the centres of the brain, there can be no doubt. At the same time, no mechanical mixture or fusion of these excitations, within common or allied areas of nervous substance, in the least degree resembles that mental synthesis which experience implies. An activity that combines under different laws from those which govern the various nerve-commotions, as they are excited in the brain by external and internal stimuli, must take place in order that *one* object may be cognized by *one* subject, — the cognizing mind.

3. *Those phenomena of consciousness which we call "memory" and "recollection" imply relations with the established molecular constitution and tendencies of the cerebral centres.* But the peculiarly *mental* phenomena, which we call by these terms, bear no resemblance to those which, so far as we know or conjecture them, are called by such terms as "organic memory," "dynamical associations," etc. Especially is it true of conscious recognition, — involving, as it does, the conscious appropriation of the present mental state, as representative of another past state, to the same one subject to whom, as its states, both that which represents and that which is represented belong, — that this is a something utterly unimaginable and inexplicable in terms of revived nerve-waves or molecular agitations of a nervous mass.

4. *The course of the ideas, and the changing tone of feeling and emotion, are related to the vital conditions of the cere-*

bral centres. But here again, mingling with all these changing mental phenomena, we find what is known in consciousness as self-control. *Self*-control is an immediate determination of the states of consciousness, and through them a determination of the states of the "body," which is to be attributed to the conscious mind as its origin or source. To speak of this unique experience as though the science of physiological psychology had disproved its reality, or had shown it actually to be other than what it obviously appears in consciousness as being, is absolutely without any sufficient warrant. To call this unique experience an "illusion" is to do violence to the science of psychology in behalf of conjectures attached, but not belonging, as verified facts or principles, to the allied science of physiology.

5. *The inherited peculiarities* (tribal, family, and sexual) *of the organism are related to the general tone or coloring of all the conscious mental life.* That differences of disposition and temperament exist, which are innate and permanent, and that these differences are dependent upon the inherited bodily constitution, there is no reasonable ground to dispute. On the other hand, we cannot adopt that fanciful philosophy which considers the mind as the builder of the body — as in some direct way fashioning to its own inherent constitution and uses the organs of the physical mechanism. But the popular impression that the mind "influences" the body, and has even, within certain limits, the power of shaping it to its needs, and of profoundly modifying its molecular structure and action, has ample warrant in the facts.

In explanation and justification of the popular impression we shall now speak further upon this point. The popular impression, as expressed in the popular language, is obviously based upon the assumption that some kind of reality exists which corresponds to the term "the mind."

This reality stands — it is further assumed — in real connections with a reality of another kind, — namely, with the body. The nature of these connections is vaguely and figuratively (always figuratively) expressed by various phrases and words. Thus, the body is frequently spoken of as the "seat" or "organ" of the mind. The one party, in this fancied dual partnership, is said to "influence" or "control" the action of the other. Sometimes, but usually not in the language of the people, the phenomena of consciousness are regarded as "products," or "resultants," or "manifestations," of the functional activity of the brain. That some kind of "bond," or "tie," or "connection," exists between body and mind, few are found bold enough to doubt.

What that is true to the facts of physiological psychology, and also defensible by that branch of philosophy which concerns itself with what men call "real," is signified by such popular expressions as these?

The Body as the "Seat" of the Mind. — The mind is commonly regarded as connected with the body by being *in* the body. This general assumption that, in some sense, the mind is in the body is yet more figuratively expressed by saying: The body is the "seat" of the mind. It is not plain at once, however, just what is meant by this figure of speech.

Experience undoubtedly justifies the popular language in regarding the mind as "in" the body, in the same sense of the words which warrants us in also saying: it is *not* in yonder bird, or star, or tree. Hence, certain now antiquated forms of philosophy represented perception as though it were a process in which the mind streams out through the avenues of sense and thus embraces the object of sensuous perception. Others thought of some image or etherealized copy of the object as streaming into the mind through the same avenues of sense. The modern study of perception, on a basis of experiment and analysis, has disproved these and all similar ways of regarding the relations of the mind to external things.

The ancients located the soul in the heart or the lower viscera, because of certain obvious relations between mental states and the conditions of these organs. The more obvious relations, however, were for the most part confined to the emotional states of the soul. We have seen that they had little suspicion of the intimate and extensive dependence of the mental life upon the constitution and functional activity of the contents of the skull. Modern science, with a sufficient array of evidence, emphasizes the dependence of mental life upon the brain.

In whatever sense, then, the mind can be said to be really "in" the body, in that sense must it be said to be really "in" the brain. But what that is real do we mean by speaking of the mind as having its seat within the brain?

Our present physiological and anatomical knowledge of the human cerebrum and its functions is unfavorable to a view which would "seat" the mind in any single and limited locality of this organ. Descartes, indeed, found in the pineal gland the special seat of the soul. We know of no special significance which this small bit of nervous substance possesses. The modern science of the localization of cerebral function has changed our entire way of considering the matter. In whatever sense the mind has its "seat" in any part of the body, in that same sense it has *various seats* for its various related activities. And yet the unity of the mind in consciousness — the thing which, above all others, the investigations of physiological psychology are powerless to explain — is not at all affected by this variety of local relations between itself and the centres of the brain.

An analysis of the popular language, in connection with the facts and theory examined in Chapters XIII.–XIV., shows us what its real meaning is. The phenomena of sensation-complexes that are localized and projected as the different areas of our own body, and the phenomena that, being tinged with feelings of pleasure and pain, are most obviously ascribed to our own soul as it states, are constantly interrelated in experience. But man is a metaphysical being. He naturally and necessarily assumes "real" existences as the subjects of these two markedly different classes of occurrences. The localized and projected sensation-complexes are attributed to one reality, — to a material body; the experiences that have an interest, because they are so suffused with feeling, are, in a peculiar way, assigned to another real being, to a "Self" or a soul. How this "diremption" of experience comes about, so far as the history of the process can be traced and explained, it is foreign to our present purpose further to inquire.

It is then a genuine metaphysical activity of the mind which is testified to, whenever the popular language speaks of the body as the "seat" of the soul. And the kind of experience which fosters and supports this metaphysical activity is the experience of localizing and projecting, in a systematic way, certain of our own sensation-complexes.

But what is meant when, in the name of modern science, we limit that part of the body, in which the soul has its "seat," to the higher nervous centres? The metaphysics of this process is essentially the same as that expressed in the popular language. But the kind of experience on which the metaphysical assumption rests is much more remote from our daily life. Its observations demand rare and refined instrumentalities; its conclusions rest upon complicated and often doubtful inferences.

Unless, however, we are ready to deny all reality to the assumptions and affirmations of both popular language and modern scientific researches, they mean essentially the same thing. Neither means that an entity called "soul" is suffused through another entity called "body," as luminiferous ether may be supposed to interpenetrate the substance of the window-pane. Neither means that an entity called soul maintains a "sitting" or other sort of posture, whether *in* the peripheral or in the cerebral areas of the entity called body. But both forms of expression assume the existence, in reality, of both a body and a soul. Both affirm that these two existences are, for certain of their activities, interdependent.

Body as the "Organ" of Mind. — Another set of relations, which are customarily assumed to exist in reality between the body and the mind, is expressed by such words as "organ" or "instrument." These terms are intended to emphasize the connection, in reality, between the ideas and volitions which arise in consciousness, and the induced movements of the muscular apparatus. But the term, as popularly employed, is plainly figurative to a high degree. An instrument, or organ, is any material medium between the masses of matter, whose shape or position we wish to change, and the movable parts of our own bodies. Or it is a means of sharpening, defining, and multiplying our sensations and perceptions of things. Or, again, it is an apparatus, by producing changes in which, we express sentiments and ideas. *With* the instruments of spade and shovel we throw up the ground; *with* pulley and lever we raise weights. *With* microscope or telescope, as organs added to the natural organ of the eye, we see things minute and near, or larger and far remote. *With* that instrument, whose name is "organ," we express our musical sentiments and ideas.

Few persons, however, will be found so crude in conception as to suppose that, in reality, when a limb is moved, an entity of some kind, called "mind," is laying some sort of material clutch — present there — upon the muscular fibre. Certainly no one, well informed enough to know of the existence and character of cerebral localization, supposes that this same entity plays, in a physical way, upon the nerve-cells and fibres of the cerebral centres.

But every form of conception, whether popular or scientific, which leads to the use of words like "instrument" or "organ" in the effort to express essential relations of body and mind, implies the same experience, and sets forth the same truths. There are two realities implied, — the body and the mind; and these two are, in reality, interdependently connected.

The Word "Connection" as applied to Body and Mind. — Much of the popular language undoubtedly implies that some "bond" exists between the body and the mind. In summing up the results of our previous researches we have frequently felt ourselves obliged to use the term "connection." Both these terms, however, like the ones already examined, are plainly of a figurative character. Of course — it needs no argument to show this — no actual bond or tie, such as we employ to make two material things act in certain desired relations, whenever they do not "naturally" so act, unites the body and the mind. But the essential truth is this: In the order of nature, the body and mind *do* naturally act under binding relations toward each other. Body and mind behave with reference to each other, *as though bound.*

Yet again, we cannot speak of any *one* bond or connection as existing between those two beings which we designate by the words, body and mind. No single formula can express all the various natural forms of their related behavior. The whole investigation of physiological psychology aims to discover as many as possible of those natural forms of relation, of those so-called "bonds" or "connections," which exist between the two. It traces inward and backward, the obvious changes in the periphery of the body, until it finds them resulting in molecular changes of mysterious chemical, thermic, nutritive, and distinctively nervous, orders, within the substance of the brain. With these molecular changes it "connects" the concurrent or subsequent mental phenomena. But such connection is no physical tie or bond. By the word "connection," we only signify *the ultimate fact that the two beings, which are the subjects of the two classes of changes, are in the order of nature causally related.*

If it should be complained that, in this way, the entire investigation of physiological psychology ends in a mystery, the truth of the complaint must be granted. The fact that body and mind are thus, in a great variety of particular ways, causally related, is an ultimate fact; — this, so far as science, with its legitimate inferences, can go. But all so-called causal relation is equally mysterious; it all partakes of the nature of ultimate and inexplicable fact. That one atom of oxygen should influence, or cause, another to act in a certain way, is also an ultimate mysterious fact. That an atom of oxygen should cause other atoms of hydrogen, carbon, nitrogen, etc., to act in a great variety of different ways, involves numerous equally mysterious and ultimate "connections."

Exertion of Energy between Body and Mind. — Modern physics has established an important principle, called the "conservation and correlation of energy." Closely connected with this principle (indeed the same thing as one side of this principle), is the assumption that the quantum of physical energy in the universe is invariable. These principles modern biology has borrowed from modern physics. Strictly speaking, however, it is only within comparatively narrow lines of even physical researches that the principle of the conservation and correlation of energy can be inductively established. And chemistry would make few indeed of its present splendid advances if it were confined to deductive predictions, under this principle, concerning the behavior of molecules and atoms in their various relations. In spite of all its serious attempts, biology, too, is far enough from the position in which it can make much use of the same principle.

Few will question the statement that any so-called influence, or causal action, of body and mind upon each other, is incapable of expression in terms of the conservation and correlation of physical energy. Energy, whether stored or kinetic, within the nerve-cells of the cerebral centres cannot become stored or kinetic in the assumed subject of mental phenomena. And, really, although we use terms of quantity to describe mental phenomena, they cannot, as *mental*, be correlated under this great physical principle with quantities of the molecular changes that occur in the brain. No mental energy ever passes over into the brain; no nervous energy ever passes over into the mind. Indeed, the very attempt to apply the conceptions and terms, so familiar to physics and so scientific when dealing with the relations of physical masses and movements, ends in palpable absurdities when the subject of treatment becomes the relations of body and mind.

In view of these and other similar difficulties, some would utterly refuse to speak of body and mind as, in any true sense of the word, *causally interrelated*. But such a refusal leaves all popular and all scientific language without any ground in reality on which to stand. We are obliged to talk as though the mind behaves thus and so, "because" of the simultaneous or previous behavior of the body, to which it naturally stands in relations. With equal confidence do we, in both ordinary and scientific terms, assert the causal action of the mind upon the body. There is as much valid reason for all this as there is for regarding any two sets of phenomena, and any two beings considered as the subjects of the phenomena, as standing in causal relations. There is as much reason for saying that my volition *causes* my limbs to move, and that the light-waves on the retina *cause* in me sensations and perceptions, as there is for saying that the earth *causes* the meteor to fall to its surface, or the sun *causes* the plant to grow by its warmth and light.

Mind and Body in Causal Relations. — We are therefore warranted in maintaining that *the changes of the human brain and the phenomena of human consciousness stand toward each other in the relation of cause and effect.* The general relation of cause and effect is far more profound and extensive in its application than the modern physical postulate of the conservation and correlation of energy. The relation of cause and effect is, indeed, the ultimate fact — itself inexplicable — by the various applications of which we "explain" all events in the world of matter and of mind. But the principle of the conservation and correlation of energy is only a valid and useful working hypothesis under which we may bring certain classes of physical phenomena.

When, then, we attempt to consider the relation of the brain and the mind without using terms of causation, we find ourselves landed in unreason through the effort to escape a fundamental law of all reason. But when we attempt to apply the physical formula (the principle of the conservation and correlation of energy) to the case of brain and mind, we find ourselves landed in absurdities of a practical as well as of a scientific sort. All the researches of physiological psychology imply that changes in the material organism and changing mental states are causally connected. All its discoveries are designed to render more precise, and to reduce to as nearly exact terms as possible, the statements of these causal relations. On the other hand, all its discoveries emphasize the complete impossibility of considering these causal relations in terms of the conservation and correlation of physical energy.

It may be said again that, in the last analysis, the foregoing conclusion makes it impossible for science to comprehend the connection of body and mind. All that we call the "science" of their relations rests back upon an ultimate fact. This is true — as true and mysterious — of the subjects with which physiological psychology deals as of those considered by other forms of science.

But what is there in the nature of the so-called "*causal nexus*" which should prevent its being assumed to exist between the body and the mind? In reply, we might ask: What do we really mean when we speak of an event, or a thing, as the "cause" of another? What do we mean when we speak of "exerting influence," or of "acting and being acted upon," as between two beings in the world of manifold existences? Nothing that the senses can discover, or the imagination depict in terms of sense. Such affirmations are born of reason; they arise from a postulate of the higher activity of the mind itself. They express in various modifications, the ultimate, mysterious fact of a relation, in reality, between those beings whose states are observed to be correlated with each other under uniform laws. And that this fact of causal relation maintains itself with reference to body and mind, there are the most abundant reasons to affirm rather than to deny.

Causal Influence of the Body on the Mind. — Speaking naturally and without prejudice, no one would hesitate to regard the body as a "cause" of the phenomena which we attribute to the subject called the mind. Who doubts that a man loses his senses, as truly as he loses a portion of his brain-mass, *because* he has been struck a blow upon the head? The stoppage of the arteries that furnish blood to the higher cerebral centres, whether by outside pressure or by embolism, promptly causes the disturbance or cessation of consciousness. The character and amount of blood circulating in these centres causes marked changes in the character and time-rate of mental phenomena. Witness the effect upon the mind of certain drugs, or of the delirium of fever. Schroeder van der Kolk tells of a patient who, when his pulse was reduced by digitalis to 50 or 60 beats per minute, was mentally quiet or depressed; when it was allowed to rise to 90 beats, his mind was in maniacal confusion. Cox narrates the case of a sick man who, at 40 pulsations in the minute, was "half-dead"; at 50, melancholic; at 70, quite "beside himself"; at 90, "raving mad." Hallucinations, not infrequently, immediately cease, when the person afflicted with them assumes the standing posture, or has leeches applied to the head.

But there is little need to enumerate facts, at this stage of our investigations, in support of the proposition just made. A large part of all the conclusions of which the science of physiological psychology consists, prove nothing whatever, if they do not prove that bodily changes are the "causes" of alterations in mental phenomena. The chapters on the localization of cerebral function, on the quality and quantity of sensation, etc., abound in facts of the order required for such proof.

The affirmation of a causal action of the body — and more especially of the brain — upon the mind does not, however, invalidate the claims of the mind to be considered a real being, or to be spiritual and free. For the *sole* account or cause of the mind's activities can, in no instance, be found in the molecular condition and changes of the brain. The full account of every mental state must refer directly to the nature of that subject, the mind itself, of which it is the state, as its cause. Even the simplest sensation is not explained solely by indicating what form of nerve-commotion in the cerebral cortex is its bodily cause. Every sensation must also be considered as a psychical activity put forth by the being called mind. There is no real incompatibility between these two ways of regarding every mental state. Indeed, every change of state in any physical being demands this dual way of regarding it. Every such change must be considered both as caused by a change of states in other beings to which it is related, and also as due to activity of that being to which as a change of state, it belongs.

Causal Influence of the Mind upon the Body.—We have an equal right, however, to affirm that mental states, changes in consciousness, are a cause of changes in allied cerebral centres, and, through them, in the other tissues and organs of the body. Speaking naturally and without prejudice, no one would hesitate to regard the mind as causally influencing the condition of the body. Even the most purely vegetative of the bodily processes are dependent for their character upon antecedent states of the mind. It is as true that melancholy causes bad digestion as it is that bad digestion causes melancholy. Care, chagrin, and ennui poison the blood. Excessive voluntary application and over-excited feeling wear away the brain. The most modern researches into the phenomena of hypnotism lend evidence to the view, that "mental suggestion" accounts for the abnormal condition and action of the cerebral centres quite as truly as the condition of these centres accounts for the strange mental phenomena which accompany this complex state of body and mind.

The entire class of phenomena which we are entitled to call "voluntary" might be appealed to in proof of the same principle. Here we might instance the voluntary innervation of an organ by fixation of attention, the dependence of reaction-time upon the will of the person reacting, the abstraction of regard from the images of sense when occupied in reflection, as well as all the more marvellous cases of self-control in enduring pain, triumphing over disease, etc.

The elevation of the bodily activities to a most astonishing precision, under the influence of high and strong artistic feeling, is also a noteworthy fact of the same order.

It appears, therefore, that the human brain is a vast collection of material molecules, whose constitution and arrangement are such as to connect them, in a unique way, with certain forms of external physical energy. But they are also capable of standing in yet more surprising and unique relations to a being of a different nature from their own — that is, to the mind. These latter relations involve a causal connection as truly as do relations of real physical beings. That material molecules and a being of the kind called mind can be causally connected is, indeed, a mysterious fact. But because of its mystery, it is no less to be acknowledged as a fact.

Finally, then, *the assumption that the mind is a real being, which can be acted upon by the brain, and which can act on the body through the brain, is the only one compatible with all the facts of experience.*

Processes involved in the Connection of Body and Mind. — All intercourse between material objects and the spiritual subject we call "Self" involves three processes. Of these one is physical, the other physiological, the third psychical. In and through these processes, external things and the subject of mental states mutually condition each other.

The *physical* process consists in the action of the appropriate modes of physical energy upon the end-organs of sense. These modes of energy are brought to bear upon the nervous portions of these organs by means of mechanical contrivances — such as, for example, the contrivances for forming an image upon the retina of the eye, or for conveying the modified acoustic impulses to the organ of Corti in the inner ear. With this kind of processes the science of physics — but only by a great increase in the refinement of its methods — may hope to deal more successfully in the near future.

The second process consists in transmuting the physical energy into a *physiological* process, a nerve-commotion within the nervous system; and in propagating this nerve-commotion along the proper tracts and diffusing it over the various areas of the brain. It belongs to the science of physiology to investigate and describe this process and its laws. More particularly, the science of this process is called "general nerve-physiology," with its several departments of more highly "specialized nerve-physiology."

The third process is *psychical;* it is a process which is a psychical event, a forthputting of the peculiar energy of the mind. It is directly correlated with the physiological process only when the latter has been realized in certain cerebral areas. The psychical process cannot be explained wholly as a resultant of the cerebral physiological process; yet it is an activity of the mind which is conditioned upon that process. When, for example, the particular mental process is the perception of some "external" object, it is no less truly a psychical process. The mind creates its own objects; presents itself with its own presentations of sense; acts to put forth, as its own product, that which it knows as "not-itself." But it accomplishes all this as dependent upon processes that take place in other beings, and with the assumption of the existence of such beings, to which it stands in relations of cause and effect.

CHAPTER XX.

THE NATURE OF MIND.

THERE can be no doubt that the popular impression is in favor of affirming the reality, unity, and spirituality (or *non*-materiality) of the human mind. Indeed, so long as we take only the popular point of view and employ only the language which is customary to it, great difficulty is experienced in even expressing such inquiries as the science of physiological psychology suggests. It is, however, the scientific study of those phenomena which show a special dependence of mental states upon nervous conditions which disturbs the popular impression. Does science, then, end in destroying this impression? Or, does it not, after disturbing and modifying it, reinstate it, substantially unchanged, upon much surer and more defensible foundations?

The Question as to the Reality of Mind stated. — Although the general confidence of men in the reality of their own minds is without doubt, there is no more obscure and puzzling question than this: In what does this reality consist? In other words: What is it to be *real* as all men believe their mental "selves" to be real? But this is a question which it belongs to the metaphysics of mind, as an important department of philosophy, fully to discuss. As such, it does not properly belong to even the final considerations of physiological psychology.

There is a form, however, in which the debate over the reality of the mind may properly be considered as connected with the subject we have been studying. This form is proposed under the heads of the arguments for and against what is called the "materialistic" view or hypothesis. For the materialistic view of mental phenomena denies the popular impression, — namely, that such phenomena are to be referred to the mind as the subject or ground of them all. On the contrary, it affirms that the material substance of the living and active nervous system (especially, or wholly, of the brain) is the only reality concerned in the production of these phenomena. The *mental* phenomena, it holds, are phenomenal of, manifestations of, the only "real" subject, which is in its view — as we have already said — not mind, but the wonderfully constituted and complex system of material molecules within the bony cavity of the skull.

Is this view which we have called "materialistic" justified by the facts and laws of physiological psychology? Or is, on the contrary, that view justified which regards the mental phenomena as rightly assigned to a real being to be called "the mind"; and yet regards this real being as acting in causal relations with the material substance of the brain?

It will be recalled that we have already in part answered the foregoing questions by an argument against the materialistic view. This argument will now be resumed and briefly continued.

Difference between Nerve-commotions and Mental Phenomena. — It is scarcely necessary to urge the fact that states of consciousness are not identical in nature with molecular agitations in the higher centres of the brain. Not even the most pronounced materialists would venture to affirm their identity. Minute movements, or chemical and vital changes, in the molecules of the cerebral mass differ totally, as phenomena, from states of sensation, of perception and ideation, with their accompanying tones of pleasurable or painful feeling.

Even less, perhaps, would any one think of identifying the most complicated and ample nerve-commotions with those trains of thought which result in solving a mathematical problem, or with those feelings of adoration and affection which some men experience on contemplating the idea of God. Mental states, on the one hand, are known only as states of consciousness that are *mine;* but states of material molecules are conjectured as changes occurring in *my brain.* The complete "incomparability" of these two classes of phenomena is denied by none.

Modern science tends to regard all physical events as modes of motion — alterations in the relations of material atoms or masses to each other in space. This is as true of the brain of the philosopher or of the saint as it is of the falling meteor or the upturned clod of the valley. The very assumption which underlies materialism — namely, that the brain is an extra-mental and material being which undergoes changes independent of all mental perception or conception of these changes — seems to involve most unequivocally the incomparability of nerve-commotions and mental phenomena.

Mental States not "Products" of the Brain.— In the effort to substantiate the being of the nervous organism and, at the same time, deny that of the mind, various terms may be employed to express the relation between the two. Among such terms the word "product" occurs. We hear it said that the brain — at least the psycho-physical centres — "produces" the phenomena of consciousness. It is impossible, however, to give any satisfactory meaning to the word "product" in a connection such as this. By this word we ordinarily understand the new form into which some material substance is shaped by the action upon it of some piece of mechanism. We may, indeed, call certain secretions of the body the "product" of the tissues which secrete them, in somewhat the same way as that in which we speak of the product of the field or of the loom. But only the coarsest and most undiscriminating materialist could regard himself as saying what is really valid when he represents states of knowledge, feeling, or volition, as in this sense of the word, the "product" of the brain. When, too, we are told that the brain "throws off" the mental phenomena, as a kind of surplusage — so to speak — of its more legitimate form of activity by way of molecular motions, we listen to words to which we are absolutely without power to assign any intelligible meaning.

There is another and more plausible use of the word "product" to describe the connection between the cerebral centres and the phenomena of consciousness. Suppose a system of material molecules to be acting under relations to each other which are determined by the constitution, arrangement, and environment of the molecules. We may then speak of the new relations which these same molecules assume as the *product* of their previous constitution and arrangement, together with whatever influences act upon them from without (their environment). Thus the functional activity of the cerebral centres, at each moment, may be regarded as the product of the nervous substance of the centres themselves.

But this use of the word would only explain each momentary condition of the brain as arising out of its physical constitution and previous physical condition. The explanation is perfectly legitimate; it is the business of the physiology of the cerebral centres to carry such an explanation as far as possible. Doubtless all the nerve-commotions, all the molecular changes, in the cerebral centres are, at each moment, capable of being regarded as "products," under a mechanical theory, of antecedent changes. If, however, such a mechanical theory of the behavior of the brain, regarded as a system of material beings, could be perfectly adjusted to the principle of the conservation and correlation of energy, we do not see how it would enable us to regard the behavior of the mind — the phenomena of *mental* states — as "products" of the same antecedent changes. Out of nerve-commotions, as their product, other nerve-commotions come. But how are the phenomena of knowing, feeling, and choosing rendered any less incomparable with the molecular changes of nervous matter by speaking of them, too, as *products* of the substance of the brain?

Nervous Changes as Antecedents of Mental Phenomena. — But surely, it will perhaps be said, the happenings of mind, the so-called states of consciousness, are dependent upon the changing conditions of the brain. Precisely so: but this does not alter the necessity of assuming the reality of mind, as the being whose states change, though in dependence on other beings of a material kind. On the contrary, if this question were to be referred to metaphysics we should say that, to be the subject of states which change in dependence on the changing states of other beings, is in part the essence of all reality.

The investigations of physiological psychology furnish abundant proof, on the other hand, that mental phenomena are the regular antecedents of changes in the cerebral centres, and through these changes, of changes in the other bodily organs. Indeed, the more comprehensive, minute, and profound its investigations are, the more convincing does the evidence to this effect become. On the whole, there is as good reason to regard the mind as a reality which influences, or acts upon the body, as to regard the body as influencing, or acting upon, the mind.

To emphasize the fact that nervous changes are the regular antecedents, or causes, of mental phenomena, and to deny that mental phenomena are also changes of states in a real being, which we call the Mind, is therefore to treat the scientific data in a one-sided way. It is, indeed, to treat the psychical subject of states with more disrespect than physics shows to the mass or the atom. For every material mass or atom is dependent upon the behavior of some other similar mass or atom, for the character of its own changes. But physics does not, on this account, deny its reality. In its turn, by its own behavior, each mass or atom also furnishes regular antecedents, as causes, for other changes in the very beings on which its own behavior depends. *These* other beings, too, are dependent upon it for the way in which they behave. What valid reason can be given, why the reality of mind should be sunk wholly out of sight, in the supposed behalf of the material molecules of the cerebrum? Surely the souls we know we are should receive as much consideration as the elements of that pulpy mass we call our brains.

Superiority of the Mind's Claim to Reality.—For, in truth, the claim of the mind to a real and independent existence is, in some respects, unique. It is far stronger than the claim which can be made for any of the existences with which physical science deals. The materialistic theory, of course, assumes the very opposite of this. It assumes that every mental phenomenon is to be accounted for *solely* as a manifestation of changes going on in bodily reality,—in the psycho-physical centres of the brain. Nothing—says the theory—can happen by way of conscious sensation, perception, æsthetic, or religious feeling and belief, abstract conception, or so-called free choice, which does not find its only real explanation in the equivalent changing states of the nervous system.

Our first impression on considering the foregoing theory is one of surprise at its audacity. We have had frequent occasion to remark the extraordinary difficulties which accompany the effort to establish on scientific foundations almost every subordinate principle of physiological psychology. Even in those branches of its inquiries in which the methods of physical science can be most successfully employed (*e.g.* Weber's law, the phenomena of reaction-time, etc.) assured results are slow of attainment. Even in such branches great caution is requisite to guard against too hasty generalizations. But this theory proposes to clear all barriers with a single leap, and to establish on the other side of them a complete speculative science of the mind on a basis of principles that are recognized as applicable (and even then, not always without hesitation and doubt) only to physical phenomena.

But the theory of materialism is not simply inadequately founded. It is opposed, not only to the popular impression (which assumes the reality of the mind, and knows nothing, except by hearsay, about the existence of the brain), but also to certain conclusions of psycho-physical science.

The incomparability of the two classes of phenomena (molecular agitations of the brain and states of consciousness) we have seen to be generally admitted. The causal relation, or dependence under law, of the two, has been shown to be a legitimate conclusion of science. But the independent (in some sort) development of the mind — its life and growth as a non-material entity, under forms and laws of unfolding that are unique, constitutional, wholly peculiar to itself — is also a legitimate conclusion of the same science. In proof of this statement we may fitly appeal to certain facts treated in the preceding chapters.

Non-correlated Factors of Mental Life. — All mental life rests upon a basis of sensory-motor activities. The term "sensory-motor," however, may be applied either to physical or to psychical changes. As applied to physical activities, the science of physiology considers the data and laws; as applied to psychical phenomena, the term designates the sensation-elements, the feelings of effort and strain, etc., which enter into all our life of the body. Between these two classes of activities "correlations," in the stricter sense of the word, exist. The kind, degrees, time-rate, and "local coloring," of the psychical factors depend upon the kinds, quantities, time-rate, and locality of the physical antecedents.

But the life of the mind cannot be described solely in terms of the production, combination, reproduction, and association of sensory-motor factors. The attempt to do this induces the customary alliance between materialism and sensationalism; these two are inclined to go hand in hand, as theories of mental life. The latter endeavors to expel from existence those forms of mental activity for which the former finds it most difficult, most impossible, to account.

But a thorough analysis of mental life discloses other forms of activity than those properly called sensory-motor; and these forms not only do not find their full explanation in the changing states of the brain, but are not even conceivable as correlated with such states. For example, an increasing amount of the sensation of pressure *is* not identical with an additional gramme of metal laid upon some area of the skin; but the changes of quantity in the sensation of pressure are correlated, under psycho-physical law, with the increase in the number of grammes. Into my *perception* of the piece of metal, as a "Thing" causing my sensation, however, there enter forms of purely psychical activity that cannot even be conceived of as thus correlated.

For certain fundamental assumptions, or beliefs, enter into all perception by the senses. No perception is a mere combination of sensation-complexes, representable in terms of correlated changes of stimuli and of nerve-commotions. Perception is a knowledge of "Things." No "Thing" is known as a mere grouping of sensation-complexes. And whatever account one may choose to give of their nature and origin, there can be no doubt that various assumptions and beliefs are implicated in all knowledge of things. The knowledge of perception, then, involves an activity of the mind which is *sui generis*, — an activity into the performance of which the mind develops; and which, although it always rests upon a basis of correlated physical changes, is not, as such, representable as the equivalent, or correlate of physical changes.

Things are known as "real"; they are believed to be the "subjects" of attributes, to *have*, and not to be, the attributes. They are conceived of as acting on, and as being acted upon by, each other; they extend in an empty space, which is assumed to be self-existent and independent of the things. All this, and much more of the same sort, is implicated in those mental acts which are often falsely conceived of as the mere passive reception of impressions; or as the combination, under terms dictated by physical mechanism, of sensations and feelings of bodily strain. But, in truth, all this and whatever more is of the *same* sort, — we repeat, — implies being and action that are absolutely incapable of representation in terms of such mechanism. Nor can the varying degrees and time-rates of the movements of this mechanism be conceived of as correlates of these modes of the mind's behavior.

What is true of perception is true of all the developed mental life. Indeed, the form of mental life we call perception, implies the exercise of the so-called higher faculties of mind. Physical changes in the ideo-motor centres of the brain are, no doubt, strictly correlated with certain factors in that complex form of the mind's acting to which the name of "memory" is given. Here, too, a faded and weakened sensation, revived as a memory-image, may be regarded the psychical equivalent of a weakened similar molecular agitation in the same ideo-motor centre as that where the physical basis of the original sensation was laid.

But of what physical changes shall that conscious recognition, which is the *spiritual* essence of all acts of developed memory, be regarded as the correlate?

Serious consideration of such a question as the foregoing throws us into the same state of mind as that in which we find ourselves when we ask: How many foot-pounds is the equivalent of a true mother's love? or, How many cubic yards represent the greatness of the thoughts in Newton's "Principia"? My memory-image of the sensations, given me by a certain colored object, is — to be sure — no more *identical* with the cerebral brain-commotions on which it depends, than were the original sensations identical with those original brain-commotions on which they depended. But the image may be said to be, as respects quantity, quality, local coloring, etc., *correlated* with the revived physical changes on which it depends. On the contrary, the spiritual fact that I consciously recognize this present experience called memory as representative of my past experience, and that I attribute both present and past state to the same self, — all this implicates modes of mental life which cannot even be conceived of as having any physical correlates.

Reality of the Brain and its Processes. — It cannot escape the acute thinker that the materialistic hypothesis secretly assumes the reality and causal activity of the cerebral substance and of the physical changes which occur in it. But scepticism can readily call this assumption in question. And, indeed, the history of philosophy shows that unprejudiced reflection leads much more directly and surely to doubt about the reality of matter than about the reality of mind. Even the science of physiological psychology — at least in some of its aspects — tends to emphasize that doubt with which the record of speculation is so familiar. For this science shows us how very far is the most immediate perception of the material substance called brain, from being a faithful copy of any real existence.

How — to put our doubt into the form of a concrete inquiry — does the holder of the materialistic hypothesis know that the patient, whose mental phenomena are abnormal, has a brain to whose diseased condition he may refer this departure from the correct mental standard? Only by inference from a very few cases of post-mortem, it may be, to a general conclusion respecting all human bodies. But inference and conclusion are mental activities, — modes of the behavior of conscious mind. Inference brings us to valid conclusion, and conclusion to real existence is trustworthy, only as reason puts confidence in her own laws. These laws are the constitutional ways of that spiritual procedure on which — in the last analysis — all confidence rests.

Suppose, however, that those observations and inferences in which the science of physiological psychology delights were indefinitely extended. Suppose that all the sensory-motor functions were definitely localized in their proper cerebral areas; that the laws of the association of these areas were thoroughly comprehended; that the "nerve physiology" of the brain had developed in scientific exactness so far that the movements of each molecule of its substance could be predicted as certainly as can now the movements of the planets. In brief, let it be taken for granted that the deficiencies of knowledge which we have encountered everywhere in our study of this subject have all been, as fully as is conceivable, supplied.

A completed science of physiological psychology, as such, would not in the least degree more firmly establish the real existence of any single brain and its processes. A completed science would still be — what the very word "science" indicates — a system of spiritual activities, to be assigned to the subject, Mind.

Of course it must be understood that all *science* is based upon observation — minute, painstaking, verifiable, comprehensive. But observation itself is a spiritual activity, involving immensely complicated psychical factors, implying numerous assumptions, beliefs, and other modes of the behavior of the mind, which are not capable of being represented by, or strictly correlated with, those cerebral changes with which physiology deals.

We have, then, far more direct and verifiable knowledge of the reality which we ourselves are, as conscious minds, than of that hypothetical reality which materialism gives to gyrating, swinging molecules in the centres of the cerebrum. If one were determined to reduce all being and action, in reality, to either of those two sets of terms with which physiological psychology assumes to deal, one must certainly choose the psychical rather than the physical, the terms represented by the noun rather than the adjective, in the compound title.

Reality of Mental Development. — That the words, "development of the mind," stand for a real process, there can be no reasonable doubt. What is true of every developed mental activity is, even more palpably and emphatically, true of the entire course of mental development. It cannot be adequately described as a mere series of more and more complex combinations of psychical factors of the sensory-motor type. The difference between those inconceivably simple activities in which mental life begins and the more mature and highly developed mental activities is not a difference of degree alone. Newton or Kant, as a mind, is far more unlike the infant than the latter is unlike one of the lower animals. There is much more which is companionable and mutually intelligible between a man and his dog than between a man and his newly born child.

The changes which lie between the first and lowest, and the more mature and highest things of human mental life occur according to a plan. The life of every mind is capable of being made the subject of a history. This history has its epochs and crises; it has, as well, its periods of more steady and unobtrusive growth. But, on the whole, it implies the development of that real being, whose manifestation is indeed related to the growth and activity of the cerebral mechanism, but whose character is unique among all developments — the so-called "human Mind."

Nor does the uniqueness of the mind's development consist alone in that admitted incomparability of the phenomena of conscious sensation to all physical phenomena, to which reference has already frequently been made. In all developments of a physical sort, — even including those with which biology deals, — the factors which take part in the development are themselves really existing entities, regarded by science as endowed with natures and powers innumerable of their own. The development of living things, including the development of the nervous system itself, is, according to science, nothing but the more and more complicated and planful concourse of "the atoms." These atoms are really existing beings. But simple sensations, and sensation-complexes, and elementary feelings or "feelings of feelings," and memory-images, etc., although they are regarded by mental science as factors in mental life, are not really existing beings at all. And every attempt at a system of psychology which treats them after the analogy of the elements of a physical development overlooks the entire nature of the problem to be solved.

The life of the mind, as it manifests itself for scientific study, is a succession of "fields of consciousness." None of these so-called "fields of consciousness" can be considered as accounting for itself. All of them are forthputtings of that living being which is the subject of them all. They fade into each other; they enlarge and diminish in circuit; they succeed each other with a varying time-rate. Psychological science analyzes them into their hypothetical factors; it tries to determine the uniform conditions of their formation, and the laws according to which they follow each other. It finds them all hung together, as it were, upon a single thread,—upon the metaphysical, the shadowy but necessary, assumption of the existence of one entity, the soul, whose states they all are. No self-consciousness is so penetrating and lively as to envisage this entity in its pure being, or naked simplicity, as a subject of all the states. But every act of self-consciousness *is* a reference of some state to this assumed subject of them all. And science can do nothing with the phenomena of mind without virtually assuming that being whose life and development binds together its own succession of "fields of consciousness," so-called.

The attempt to regard the planful unfolding of fields of consciousness, which constitutes the life of the mind, as merely the resultant of a physical evolution of the nervous system, involves a constant abuse of terms. It makes inevitable that mistaking of figures of speech for scientific truths, against which we have already protested once and again. Terms which apply well enough to a biological evolution, when applied to the development of the mind, have no intelligible meaning at all. The word "development" itself, when applied to the mind, means something entirely different from the same word when applied to an organic structure like the cerebro-spinal system. At every step we have to check our descriptions of the growth of the soul's life by asking: "Precisely what, then, is it that we mean?"

But even if we disregarded the bearing of such a process of misleading substitution in the meaning of terms, we should still have valid reasons for affirming the reality of the mind's unfolding life. For the process of this unfolding, so far as we really know in what it consists, and upon what physical conditions it is dependent, does not keep equal step with the evolution of the nervous system. It is indeed customary for psycho-physical science to assume that mind and brain develop, as it were, hand in hand; and that the dependence of the former upon the latter is so strict as to make all mental growth really an expression of a physical evolution. Still, on this point, we believe that the popular impression emphasizes certain facts which the ordinary scientific hypothesis is apt to leave out of account.

For example, at the time of birth the mind appears almost or quite wholly undeveloped; although the brain of the full-grown embryo is, as respects both structure and functions, a highly developed affair. The human infant has by far the most complexly organized and fully equipped nervous system of any of the young animals. But it has, properly speaking, little or no mind. It is a truly significant figure of speech which regards the *mind* of the infant as yet unawakened; as, indeed, waiting to be aroused and set to the work of combining and interpreting those sensations which are called forth by the excitation of its nervous system.

Nor do we know of any valid reason for disputing the apparent truth that, immediately after birth, the infant's mind develops with a more rapid step than is taken by the organic evolution of the brain. That the brain grows with a marked rapidity, not only in gross weight but also in complexity of structure, during the first year of life, is a significant fact. That the sensory-motor factors of psychical growth are dependent upon, and correlated with, this physical growth, we do not for a moment question. We also regard as entirely plausible the view, that innumerable "dynamical associations" are rapidly forming themselves in the child's cerebral hemispheres.

But, on the other hand, a comparison of the character of the mental life at the close of the first year—its unfolding of the powers of perception, voluntary attention and abstraction, under those constitutional norms which philosophy calls the "intuitions" or "categories"—with the absence of all really mental life at birth, suggests another view of the case. The evolution of the brain is not a complete measure, much less is it a complete explanation, of the growth of the life of the mind.

Similar arguments against the view which regards the mental development as only an expression or resultant of the organic evolution of the brain, might be derived from other periods and phases of life. It should never be forgotten that when we are describing the character and causes of mental development in terms of a spiritual reality and a spiritual life, we are speaking of that which all men know. Mental curiosity, control of attention, careful and comprehensive judgment, sound moral purpose—these words represent terms of universal and undoubted experience. That the development of the mind depends upon, and consists in, these things, is beyond all question. That these things are *only* the expressions or resultants of organic brain-changes, is a hypothesis which most men find it difficult to comprehend; and which, in our judgment, no man has any right to propose as a scientific necessity or even as a valid scientific faith.

We regard the following statement, then, as justified: *The development of mind can only be explained as the progressive manifestation in consciousness of the life of a real being, which, although taking its start and direction from the action of the physical elements of the body, proceeds to unfold powers that are* sui generis, *according to laws of its own.*

The mind is a "real" being in the highest sense in which any finite being can be said to be real. Indeed, its claim to be considered real is more indisputable than the same claim as put forth for any material thing; it is unique. The reality of mind underlies and makes possible all our knowledge of other real beings; and all our assumptions as to the existence of such beings. It is only on condition of granting its reality, in the highest sense of the word, that we can affirm the reality of other beings.

Unity of the Mind. — Among the terms by which we characterize the peculiar nature of that being we call the mind, there is none more important than the term "unity." The popular impression regards every person, every soul or mind, as *one*, in a perfectly unique way. It is not difficult to make clear to the popular impression that we may speak of all material existences as, at the same time, one and many, — according to the point of view from which they are regarded. In the study of perception it was evident that the unity of any object of sense is imparted to it by a constructive, synthetic action of the perceiving mind. Molecular science at once proceeds to analyze the object of perception into a countless, an inconceivably great, number of constituent elements. The elements are regarded as even more truly units than is the object of perception itself.

The physical unity which science thus allows every object to have is gained only as its constituent elements are temporarily held together by various so-called "forces," according to a variety of forms called "laws." The only unity, in the stricter sense which physical science recognizes, is that said to belong to the atom; but in what this unity consists it is difficult to make clear to the mind. Indeed, the trained imagination of the physicist is scarcely adequate to depict the nature of this hypothetical unity.

Mental Unity not Analogous to Physical. — Whatever kind of unity physical science may finally succeed in indicating for the individual atoms, it is obvious that such atomic unity furnishes no fitting analogy for the case of the mind. Indeed, we ought here to reverse the entire order of procedure. The unity which the atoms are assumed to have, is due to the unifying act of the mind which thus conceives of the atoms. Whether these conceptions fitly represent any *extra*-mental realities, we do not now inquire. But whether they do, or not, there can be no doubt that the only atoms known are the atoms conceived of (as real, or not); and the only being that conceives of atoms, or of anything else, is the mind.

The foregoing fact does not necessarily favor that old-fashioned hypothesis which regarded the unity of the mind as somewhat analogous to the unity of a homogeneous and eternally unchanging material substance. Indeed, modern physical science does not regard even the atoms as "unit-beings," in such a meaning of the word. It was the theological interest in the attempt to place the immortality of mind upon a quasi-scientific basis which gained favor for this uncouth view. The argument ran: The immortality of the mind depends upon its natural indestructibility; that which is indiscerptible or indivisible is naturally indestructible; and that which is indiscerptible must be a unity in the strictest sense of the word.

It is impossible to see, however, why a physical being which has no distinction of parts, and undergoes no changes of states, is best fitted to represent the unity of mind-being and mind-life. Indeed, the very opposite of this is obviously true. Comparative study shows us that, as a rule, the more complex and varied is the psychical life of any animal, the more complex and varied is the grouping of that collection of organs which constitutes its nervous "*system*," so-called. But the highest unity of mental life is that which is built upon the greatest variety and complexity of psychical activities. It is man who, among all the animals, has by far the best claim to be considered a "unit-being," as regarded from the psychological point of view. But it is man who has also the most elaborate and complicated development of material organs, — systematized into a cerebro-spinal axis and crowned by that peerless structure, a human brain.

Nor is this cerebro-spinal nervous system, which forms the physical basis of the unity in variety of man's mental life, a homogeneous and unchanging mass. Far from it. No other portion of the bodily substance demands such a copious blood-supply; undergoes such rapid and important changes with respect to those "dynamical associations" on which the psychical habits of memory depend; and is, in general, so ceaselessly active in producing inconceivably complex molecular variations in its own condition and constitution. Corresponding to this physical system of innumerable interacting elements and parts is an almost boundless variety to the sensory-motor psychical life. For, as we have already seen, certain single senses are capable of hundreds of thousands of sensations that can be distinguished by minute variations in quantity, quality, and "local coloring." Or, more properly speaking, in response to the excitation of this wonderful nervous mechanism in a countless variety of ways, the soul puts forth a corresponding variety of those forms of manifestation which are peculiar to its life.

But all this is far from being incompatible with that unitary nature and existence which is possessed by every human soul. In spite of what we might argue as to the possible or impossible in such a case, the fact remains that, in the order of nature, this very being which has such an inconceivable complexity of physical and psychical activities is a "unit-being," in the very highest sense of the word.

The unity which the mind possesses is undoubtedly dependent upon memory and self-consciousness. It is that spiritual unity which implies the power of knowing *one's self*,—of having states not only, but also and chiefly, of referring these states to the unity of Self, and of distinguishing, in consciousness, that Self as a unique consistent development, from all other selves and from all things. So peculiarly is this a function of the developed mind, or soul, that the words, *a* mind, or *a* soul, are absolutely devoid of meaning unless they are understood as implicating this.

It is quite possible, indeed, to raise that sceptical question, of which Kant makes so much in his immortal "Critique of Pure Reason." After all,—we may ask,—*is the mind in reality one;* or does it only, when normally active, *seem to itself to be one?* The valid reply to this question is as follows: The unity of a self-conscious rational life *is* the highest and realest of all conceivable unities. In other words, to be a developing mind, with memory, reason, and self-consciousness,—this is to be really one. It is this unity, which the mind undoubtedly has in self-consciousness, that is alone worth contending for. And if the mind were really—that is, regarded as *out of* its own consciousness of self—one, and yet two or more *in* consciousness, it would be no better, but rather the worse off. If it were really one, but could not appear to itself as one, could not be aware of its own change of states, and attribute them to the one Self, which is the subject of them all, its unity would be of no value.

Once more: a thorough metaphysical analysis would probably show us that the unity which we attribute to things is never more than a pale shadow, or faded type, of the unity which we know ourselves to have. Physics, indeed, regards the atom as the only unity, in the strictest sense of the word. But this so-called "strictest sense of the word" is itself (probably) copied from that type of all reality, which is the unit-being, Mind. Only as the mind of the physicist projects, into the hypothetical being of the atom, the attributes of its own life, can he call the atom a unit, in "the strictest sense of the word." This is done with that recognition of a kinship of all beings with mind, which, after all, enters into every scientific conclusion or hypothesis.

Spirituality of Mind. — The question whether we are to speak of the mind as "spiritual" or not, scarcely merits the grave and lengthy discussion to which it has often been carried. "Materiality," as predicated of any real being, is only an abstract and complex term, summing up a number of so-called attributes. The word "attributes" is an abstract term signifying the uniform ways of the behavior, as known to us, of individual things.

Now, if we understand the term "materiality" correctly, we cannot think seriously of applying it to the mind. For the attributes which it covers are such as extension, impenetrability, mass, etc.; and only in a figurative way can such terms as these be applied to the subject of psychical states. If, on the contrary, we use the term "spirituality" as an abstract term to cover those attributes which things, as perceived by mind, do not possess, but which minds know themselves as possessing and exercising; why then, of course, we must affirm the spirituality of mind.

As soon, however, as we attempt to conceive of the substance of mind after the analogy of some ethereal extension, some more than ordinarily subtile expression of a substratum common to all beings, we lose our right both to affirm the spirituality and to deny the materiality of mind. Nor can we hope scientifically to vindicate for the mind such "spirituality" as would be implied in its being freed from all relations to things, or from dependence for the modes of its being upon the material substratum of the brain. How spirit, in the meaning of unembodied mind, would perceive, and feel, and think, and will, is a question toward the answer of which psycho-physical science enables us to make no beginning at all.

The subjects which we have been considering have a certain legitimate bearing upon speculative inquiries into the first and the last things of Mind, — its origin and destiny, its mortality or corruptibility. Physiological psychology cannot explain the being of mind as arising out of the development of the physical germ from which the bodily members unfold themselves. It shows no decisive reason against the belief that such a non-material and real "unit-being," as the mind is, should exist in other relations than those of its present admitted dependence upon the structure and functions of the body. But we have already, perhaps, somewhat transgressed the limits which most authorities would set to legitimate conclusions from this science. Questions relating to the origin and destiny of that subject of all the psychical states, whose reality and unity we believe capable of defence on scientific grounds, must be left to Rational Psychology, to Ethics, to Metaphysics, and to Theology.

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